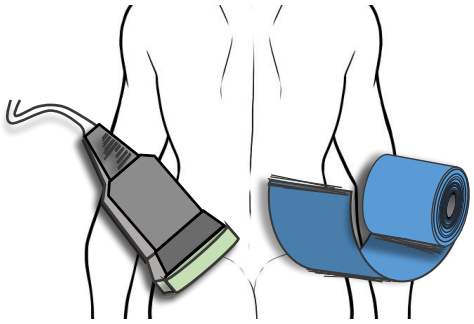
Queen Mary
University of London

THE EFFECTS AND MECHANISMS OF KINESIOLOGICAL TAPING IN PEOPLE WITH LOWER BACK PAIN

Submitted in part fulfilment of the requirements of the degree of
Doctor of Philosophy



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Collaborators

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Publications and conference papers

Journal Article

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TU, S.J., WOLEDGE, R. & MORRISSEY, D., 2015. Measurement of the effects of Kinesio-Taping in vivo thoracolumbar fascia movement using ultrasound: Method development and observational study. Journal of Bodywork and Movement Therapies, 19: 667.

TU, S.J., KHAKWANI, A. & MORRISSEY, D., 2016. Does tension of Kinesio-Taping produce effects in the underlying softtissues of the thoracolumbar area? A cross-sectional observational study using ultrasound. Manual Therapy, 25: e136.

Conference Paper - *Oral presentation:*

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Tu S.J., Woledge R. & Morrissey D., 2015. *Measurement of the Effects of 'Kinesio-Taping' in Vivo Thoracolumbar Fascia Movement Using Ultrasound: Method Development and Observational Study.* Fourth International Fascia Research Congress, Washington DC, USA. (Winner of JBMT Abstract Award)

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DEDICATION

I dedicate this work to

Professor Roger Woledge (1938-2015)

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ABSTRACT

Kinesio-Taping (KT) is increasingly used to treat low back pain (LBP). LBP is a common disorder with high lifetime incidence and recurrence which is complicated by variable treatment effects and unclear mechanisms. The overarching aim of this thesis was to determine whether biomechanical tissue responses could be identified and then used to determine subgroups of responders or non-responders to KT. Changes in thoracolumbar fascial thickness, structure and shear strain are associated with LBP. Methodological development was required and delivered a reliable, valid, in-vivo measurement technique to enable quantification of lumbar soft tissue biomechanics. Three-dimensional ultrasound videos with known orientation and position were recorded from the thoracolumbar tissues while participants performed range of movement tasks. Surface electromyography and kinematic data were collected. An automated algorithm using cross-correlation to track contiguous tissue layers across sequential frames was developed and applied to process videos. A rapid systematic review was conducted and confirmed the lack of KT efficacy, in contrast with observed popularity. The first observation study indicated that normal subjects had some tissue layer specific changes in movement with KT application. Subsequent studies of participants with LBP showed reduced superficial tissue movement compared to controls, but MANOVA showed that KT did not change either group's overall soft tissue biomechanics. Interestingly, overall soft tissue biomechanics responded differently among the small subgroup of participants with LBP who reported immediate, albeit minor, pain relief. This thesis shows that there are some effects of a common KT procedure on the lumbar soft tissues which are not yet robustly proven enough to be clinically applicable. Future study is warranted on those whose condition immediately benefits from receiving KT application to reveal if this mechanism can be developed and used to improve the immediate treatment response for those with LBP. Further, the dynamic tissue measurement method developed in this project should be considered as a transferable tool which has the potential to be applied to study effects and mechanisms of the other therapeutic modalities.

ABBREVIATIONS

ADC	Analogue-to-Digital converter
Ag/AgCl	Silver/silver-chloride
ANOVA	Analysis of variance
CI	Confidence interval
CODA	Cartesian Optoelectronic Dynamic Anthropometry
df	Degrees of freedom
DICOM	Digital Imaging and Communications in Medicine
EMG	Electromyography
ES	Effect size
Flexion-relaxation	FR
GUI	Graphical user interface
HQ	High-quality
I/O	input and output
ICC	Intra-class correlation coefficient
KT	Kinesio-Taping; Kinesiological Taping
K-tape	Kinesio-tape; kinesiological tape
LBP	Lower back pain; low back pain
LED(s)	Light emitting diode(s)
LOA(s)	Limits of agreement
LQ	Low-quality
MANOVA	Multivariate analysis of variance
MRI	Magnetic resonance imaging
ODI	Oswestry Low Back Pain Disability Index
PEDro	Physiotherapy Evidence Database
QMERC	Queen Mary University of London Ethics of Research Committee
RCT(s)	randomised control trial(s)
RF	Radio frequency
RMDQ	Roland Morris Disability Questionnaire
ROM	Range of motion; range of movement
SD(s)	Standard deviation(s)
sEMG	Surface electromyography

SENIAM	Surface EMG for Non-Invasive Assessment of Muscles
SMD	Standardised mean difference
TTL	Transistor-transistor logic
VAS	Visual analogue scale

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CHAPTER 1 INTRODUCTION

1.1 Overview of the thesis

Kinesio-Taping (KT), which was devised in the 1970s, is a well-known therapeutic taping technique used widely in sports and rehabilitation. Over 30 years, KT has been increasingly used in clinical and rehabilitation work in most sports. For example, at the recent Olympic and Paralympic Games at Beijing, London and Rio; numerous different forms of KT were worn by competitors during different sports (Figure 1). Apart from sports, more and more clinical populations are receiving KT treatment as an adjunct to their rehabilitation. Moreover, this treatment technique has even been extended to animal treatment, such as horses (Mattos et al., 2017). However, using KT could be a fashion rather than reflecting evidence-based decision making as the general population tend to follow the trends from celebrities appearing on sports broadcasts. However, the beneficial effects and mechanisms claimed by the inventor and manufacturers have to be examined by well-designed studies. Making decisions or judgements without a comprehensive investigation and robust evidence could neglect a potentially useful therapeutic modality. There is a possibility that the persistence in use of a product or technique over decades with continual informal development risks unclear utility. The initial motivation for conducting the present PhD was to help clinicians and patients decide if they should include KT as a part of their rehabilitation treatment.

LBP is a common disorder with a high recurrence and lifetime prevalence (Hoy et al., 2010). Despite not being considered a severe disease, LBP represents a sizeable socioeconomic burden to the healthcare system and society more generally due to the costs of treatment and time lost from work (Manchikanti et al., 2009, Martin et al., 2008). The cause of back pain remains unclear in the majority of LBP cases, even though some common spinal disorders related to LBP have been defined (Videman and Battié, 2012). Most randomised controlled trials have shown that recommended treatments in current clinical practice guidelines provide only mild to moderate clinical improvements in patients with LBP (Van Tulder et al., 2006, Airaksinen et al., 2006, Koes et al., 2010). The same guidelines also state that no strong differences in effect size have been demonstrated between the various exercise-based therapy modalities or manual therapy techniques. We, therefore, continue

to require better treatments, with KT having the potential to be a useful adjunct, possibly by facilitating other treatments to be in the short term.

Figure 1. Kinesio-tape used by competitors during different sports.
(Photos collected from internet and sports reports)

The overarching aim of this thesis was to determine whether biomechanical tissue responses could be identified and then used to determine subgroups of responders or non-responders to KT. Developing this evidence-based immediate benefit and whether that effect is due to changing the movement of the skin and connective tissues. The potential impact is to guide clinicians about whether the addition of KT to usual care is beneficial.

Before conducting laboratory-based investigations, a narrative literature survey and a systematic review were carried out to guide the direction of actual experimental studies. A methodological development was therefore required to enable quantification of lumbar soft tissue biomechanics. The initial methodological development and application, which included an ultrasound-based tissue dynamic data processing and analysis algorithm and experimental protocol, were carried out in a group of asymptomatic participants. Based on the results and findings, the objectives were ultrasound based soft-tissue observations, kinematics and electromyography investigations during a variety of lumbar flexion tasks, which simulated a series of daily movement tasks, in a group of symptomatic subjects. An additional project investigated the immediate effect of KT on tissue stiffness using ultrasound elastography to further explore potential mechanisms. The project outcomes not

only provide a novel approach to underlying mechanisms of KT but may also be useful to refine therapeutic taping efficacy in clinical rehabilitation and sports performance. Even though these outcomes cannot yet be directly applied to clinical decision making, they provide a strong foundation for further works.

To start the exploration, a literature review was undertaken to examine the theoretical and factual background of the thesis, such as introduction, current application and popularity of KT followed by a summary and critique of the scientific evidence of KT. Other key factors, such as the epidemiology of LBP; the relationship between connective tissue and back pain, were also addressed. The direction for further explorations on the mechanism of KT was then identified.

1.2 Kinesiological Taping in musculoskeletal treatment

1.2.1 Popularity and research trend of Kinesio-Taping

KT was first developed in the 1970s by a Japanese chiropractor Kenzo Kase (Kase et al., 2003). Different from the other therapeutic tapes, Kinesio-tape has a novel appearance with multiple colours and prints available. In practical terms, the manufacturer claimed that KT has latex free and special design pattern of its adhesive mass which meant to reduce the risk of skin irritation. Kinesio-tape is thinner and more elastic than conventional sports tape; it can be stretched to 1.4 times of its original length. Its wide elasticity range enables KT to apply a broad range of recoil tension, mobility and skin traction to achieve different treatment purposes. Possibly due to these advantages, KT became particularly popular. Likely due to its popularity and increased clinical application, researchers have paid increasing attention to KT with the frequency of KT research featuring in Web of Science rising from four in 2007 to 108 articles per year in 2016 (Figure 2).

Following sections in this chapter provide a narrative literature review looking at a broad range of treatment effects in five common clinical outcome measurements, including range of motion (ROM), pain relief, muscle strength, proprioception and swelling control, as well as the potential mechanisms of KT application.

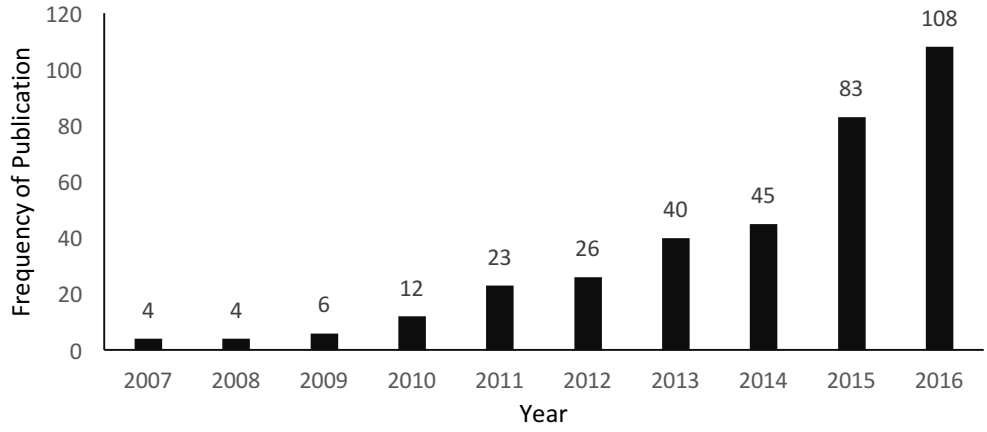


Figure 2. Annual frequency of Kinesio-taping research featuring in Web of Science
(Search key terms: kinesio AND tap*)*

1.2.2 Clinical effects of Kinesio-taping

Despite its popularity, current scientific evidence supporting the clinical application of KT is insufficient. Six systematic reviews evaluating the effects of KT on selected outcomes in different populations are currently available. Williams et al. (2012) assessed the effectiveness of the prevention and treatment of sports injuries. Mostafavifar et al. (2012) assessed the effects of KT in people with musculoskeletal conditions. Two reviews extended the musculoskeletal focus to other clinical areas, such as neurological and lymphatic conditions (Kalron and Bar-Sela, 2013, Morris et al., 2013), and the other two reviews compared the effect of KT with other forms of interventions, such as sham taping or non-taping treatments, by reviewing randomised controlled trials (Parreira et al., 2014a, Lim and Tay, 2015). These reviews have only identified insufficient, low-quality evidence about effects of KT. Weak evidence showed that KT had a benefit over placebo and active comparison therapies when used to treat a range of musculoskeletal conditions. However, the benefit was too small to be clinically worthwhile, or the trials were of low quality. Therefore, current evidence is not strong enough to support the use of KT for musculoskeletal conditions.

The above reviews were focused on identifying KT treatment effects, which is valuable in the context of designing and delivering a treatment package. However, some tentative conclusions can be drawn from reviewing studies covering a wide range of outcome measures such as range of motion, pain relief, muscle function and performance. Further, the way KT was applied may vary in order to achieve different purposes. Effects were considered in the following sub-sections, with the scientific evidence on the effect of each assessment discussed accordingly.

1.2.2.1 Effect on range of motion

Taping with rigid tape has been used in sports for years, the main purpose is to limit the range of motion in order to prevent acute or recurrent injuries (Purcell et al., 2009, Cordova et al., 2000). The reasoning to change ROM by applying KT is slightly different from rigid taping. Most studies have tried to examine if KT can increase ROM. For example, some proposed that range of motion can be increased, if KT reduced pain intensity and provided sensory feedback that reduces the fear of movement, which is associated with the intensity of pain or muscle stiffness (Gonzalez-Iglesias et al., 2009). The other possible mechanism is that increases in blood circulation after receiving KT may theoretically affect the performance of the ROM within muscle joint complex (Yoshida and Kahanov, 2007). However, no study examining the blood circulation effects of KT is available to date. These proposed mechanism is only a conjecture at the present.

Four studies reporting the effect of KT on joint range of motion were identified. These studies suggested that KT may have a small short-term effect on the range of motion for cervical extension and right lateral flexion in patients with acute whiplash-associated disorders (Gonzalez-Iglesias et al., 2009), for certain aspects of scapular kinematics (Hsu et al., 2009), improvements in range of pain free shoulder abduction (Thelen et al., 2008) and a small beneficial effect for lower trunk flexion In healthy participants (Yoshida and Kahanov, 2007). However, these results need to be interpreted carefully as only two studies were rated high methodological quality (Thelen et al., 2008, Gonzalez-Iglesias et al., 2009), while the other two studies were moderate (Hsu et al., 2009) and low quality (Yoshida and Kahanov, 2007).

The effect of KT on ROM remains unclear because only a limited number of studies on a variety of body areas have been conducted, and the results are conflicting. The two higher quality studies suggested KT may have a small short-term effect on the range of motion for shoulder abduction, cervical extension and right lateral flexion in injured cohorts. However, the results of (Gonzalez-Iglesias et al., 2009) were rather trivial and may not be clinically meaningful. We, therefore, need to have reservations about using KT for improving range of motion in injured cohorts. While in healthy cohorts, Yoshida and Kahanov (2007) suggested small beneficial effect for trunk flexion. However, it remains unclear if the beneficial truly comes from KT due to lacking comparison with placebo taping. Further studies are required to provide a better understanding of the mechanisms at play for those small improvements in range of motion.

1.2.2.2 Effect on pain relief

Pain relief is one of the key proposed effects of KT. At present, visual analogue or numerical pain rating scales remain the most common method of pain assessments in both clinical practice and research. Four studies investigated the effect of KT on pain reduction using these methods. Aytar et al. (2011) et al. reported KT was not better than sham taping in the reduction of PFPS. Three other studies reported KT produced better pain reduction in comparison with controls in back pain (Castro-Sánchez et al., 2012, Bae et al., 2013) and neck pain (Gonzalez-Iglesias et al., 2009). However, these differences are likely to be of minimal relevance to clinical practice. Despite being statistically significant, all reported improvements were small, and below the minimal meaningful clinically improvement magnitude, which was suggested by Farrar et al. (2001).

A randomised controlled trial reported a beneficial outcome with a mean (SD) 4 points reduction in back pain using the visual analogue scale from 7.1 (1.9) to 3.1 (2.8) with KT application. However, all three intervention plans, which were KT alone, exercise alone and KT combines with exercise, worked similarly, so no preferential difference was demonstrated (Paoloni et al., 2011). No control intervention groups, such as sham taping, or placebo medications, was conducted in this study. Thus, there was no way to verify whether these results were in some way confounded or traced to the retrieval history.

In short, no such robust objective assessment tool has been developed to evaluate pain due to its complex mechanisms and cause. Validating the pain-relieving effect of KT is, therefore, a challenge. Thus, shifting the focus form examining pain clinically to discovering potential mechanisms that KT may operate by could be a more promising direction. For example, targeting the possibility of applying KT on myofascial related pain, which is a typical syndrome characterized by referred pain from deep somatic structures (Procacci and Maresca, 1999), or nociceptive pain, which are related to some sensory receptor thresholds (Sterling et al., 2008) (Vicenzino et al., 2003). As these types of pain are the most likely to be related to therapies that are providing superficial stimulations. The primary focus of the present project was to observe if KT changes connective tissue biomechanics. This investigation can, therefore, contribute to the process of validating effects of KT on pain relief.

1.2.2.3 Effect on muscle strength

Apparently, KT was initially invented to enhance muscle function. Its name comes from ‘kinesiology’ which is a study of the mechanics of body movements. In measuring the effect

of KT on muscle strength, Hsu et al. (2009) assessed changes in lower trapezius muscle strength using a hand-held dynamometer, before and after taping application. A positive effect of KT was reported, with a significantly larger increase in strength in comparison to the sham taping group. This study was rated as high quality in methodology and considered as a clinically beneficial effect (Williams et al., 2012).

Fu et al. (2008) examined the effect of KT on the strength of quadriceps and hamstrings in healthy university athletes. Only one statistically significant result was reported for the high-speed concentric contraction of the quadriceps at 12 hours after taping. No statistically significant results were reported for the seven other measures of peak torque which included a concentric and eccentric contraction at two speeds. Vithoulka et al. (2010) reported a statistically significant increase in quadriceps peak torque with KT application during the eccentric assessment. However, the significant differences were about a one-way ANOVA result comparing KT, placebo tape and no-taping conditions which appeared to include a large placebo effect.

Lee et al. (2010) assessed the effect of KT on handgrip strength in 40 healthy subjects and reported a significant improvement in both males and females when KT was applied to the flexor muscles of the dominant hand. However, there was no placebo taping condition in this study. In contrast, Chang et al. (2010) reported no statistically significant difference in maximal grip strength measured under three conditions (no tape, with placebo taping and with KT) in 21 healthy collegiate athletes.

In measurements of trunk muscle endurance, a high quality study as rated by three reviews (Morris et al., 2013, Nelson, 2016, Parreira et al., 2014a), reported a significant increase in trunk muscle endurance in LBP patients with KT application (Castro-Sánchez et al., 2012). Similarly, Alvarez-Alvarez et al. (2013) also reported KT significantly extended the time to fatigue of trunk extensor muscle in healthy participants. These findings suggest that KT may influence the processes that lead to muscle fatigue and that KT has the potential to be effective in the management of LBP.

The result of these studies in muscle strength seems to be beneficial, at least there is some evidence for KT having a small beneficial effect on muscle strength or endurance. However, this beneficial effect needs to be treated with caution as there are conflicting study results. Again, mechanisms to link to these positive outcomes in muscle strength to KT applications are still inadequate.

1.2.2.4 Effect on proprioception

Wearable therapeutic accessories such as braces and taping are commonly believed to be important in rehabilitation as taping provides proprioceptive feedback (Halseth et al., 2004, Lephart et al., 1997, Morrissey, 2000). The other proposed mechanism was that the pressure and stretching effect of KT on the skin is supposed to stimulate cutaneous mechanoreceptors, which transmits information about joint position and movement, and therefore may enhance proprioception (Grigg, 1994), which is supposed to play a role in prevention of injuries (Lephart and Fu, 1995). Unexpectedly, there are not many studies which examined the effect of KT on proprioception. This may be due to difficulties in measurement of proprioception. A study measuring the error in force sensation in healthy athletes reported two positive results with respect to proprioception in grip strength (Chang et al., 2010). Apart from force sensation, another study of knee joint position sense in patients with patellofemoral pain syndrome reported insignificant results for knee proprioception (Aytar et al., 2011). Halseth et al. (2004) examined the effects of KT on ankle joint re-positioning. The KT group showed no statistically significant change in absolute error for ankle reproduction of joint position sense measurements for both plantar flexion and inversion when compared to the no taping condition. Surprisingly, there was not enough data for us to judge if KT is a beneficial tool to help proprioception clinically. Some uncertainty remains on this topic. For example, it is difficult to compare the results from healthy athletes with symptomatic cohorts; and these studies only considered a few of many types of proprioception which is a common limitation of this type of study. More research with both healthy and injured participants in this area is required to validate the correlation between KT application and proprioception.

1.2.2.5 What can KT offer for LBP care

There are two systematic reviews specifically examining the effects of KT on LBP (Nelson, 2016, Vargas Batista et al., 2014). Five studies examining the effect of KT on LBP treatments were identified (Bae et al., 2013, Castro-Sánchez et al., 2012, Kachanathu et al., 2014, Paoloni et al., 2011, Parreira et al., 2014b). Among these studies, two forms of KT were used, Kachanathu et al. (2014), Paoloni et al. (2011) and Parreira et al. (2014b) applied 'I' strips along the erector spinae muscles, while Bae et al. (2013) and Castro-Sánchez et al. (2012) applied 'star' shape taping over the painful area (Figure 3). Parreira et al. compared effects of two different tension of KT on pain and disability scale. Although no between-group difference was found, the compared approaches significantly reduced pain by 2.6 cm reduction in a 10-cm VAS scale. The other four studies compared the effect of conventional

physiotherapy in combination with KT (Physio-KT) with physiotherapy alone. Castro-Sánchez et al. reported a minimal beneficial effect of KT; however, they did not report treatment effects in comparison with the baselines. The other three studies reported significant reduction in pain and disability scales in both the combined Physio-KT group and physiotherapy only group, while the pain scale improvements were higher than 2 on a 10 point scale which can be considered clinically significant (Ostelo and de Vet, 2005). However, this evidence was not able to indicate that KT was superior to other treatments.

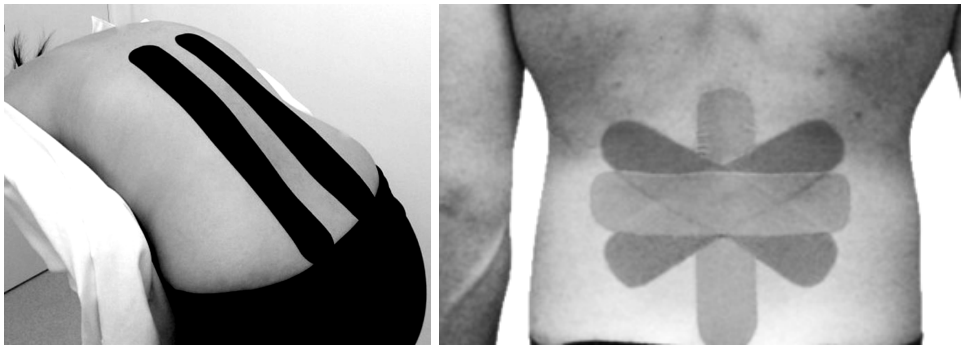


Figure 3. Example of two forms of KT used in LBP studies
Right: 'I' shape strips parallel to the erector spinae (Parreira et al., 2014b)
Left: star shape strips over the painful spot (Castro-Sánchez et al., 2012)

Based on the findings of these studies, any beneficial effect of KT on the assessed parameters may be as an adjunctive therapy for individuals with acute LBP. There are still some limitations on making robust conclusions. For example, only five trials have been published to date, which were typified by heterogeneous methodology and treatment methods. Secondly, this kind of studies inevitably relies on self-reports of pain, with the associated problems self-report bias and possible inaccurate outcomes. Some argue that such subjective measurement tools may not be sensitive enough to detect an improvement (Hägg et al., 2003). Finally, the different applications of KT being used in each study make evidence synthesis particularly difficult.

At present, the evidence cannot yet reject the null hypothesis that there is no effect, but to keep on working to address the absence of evidence and ensure a type two error is not made in across the literature are two important jobs that need to be done. A way forward might be considering sub-group comparisons among people with LBP who do and do not respond to KT application immediately, alternatively considering those known LBP covariates such as physical activity levels, in the short, intermediate and long-term; or even try to discover potential physiological mechanisms. Considering these parameters could be a potential solution for heterogenic causes of LBP and ultimately help us to draw a robust conclusion.

1.2.3 Mechanisms of Kinesio-taping

As mentioned in the last session, published systematic reviews were focused on identifying KT treatment effects, including common clinical assessments, and the results were insufficient. Probably due to the difficulty of exploring mechanisms, only a few studies investigated the mechanisms, which includes electroencephalograms (Bae et al., 2013), electromyography (Bae et al., 2013, Lee et al., 2012, Hsu et al., 2009, Paoloni et al., 2011, Słupik et al., 2007) and tissue deformation (Pamuk and Yucesoy, 2015) alongside the clinical effects of KT. The current evidence is not yet enough for a systematic review and meta-analysis. However, some provisional directions can be deduced from reviewing studies covering several mechanical investigations.

1.2.3.1 Mechanism of pain relief

Pain relief is one of the key proposed effects of KT. As per the inventor, pain relief is achieved by increasing afferent feedback through the stimulation of sensory pathways in the nervous system (Kase et al., 2003). However, I was not able to find any direct evidence to validate this mechanism. Thelen et al. (2008) stated the skin traction stimulation input of KT could be hypothesised to weaken the input from nerve fibres conducting nociception due to the gate control theory, however, this theory is rather outdated. There is another theory which can be considered related to the pain relief effect. KT applications lift the skin by creating convolutions, and this is thought to directly reduce pressure on subcutaneous nociceptors (Kase et al., 2003). However, Parreira et al. (2014b) compared KT application with and without convolutions and found a similar effect in pain and disability index reductions. Furthermore, Pamuk and Yucesoy (2015) found both lifting and compressing occurred in two regions of the skin under the same KT application. These outcomes challenged the proposed mechanism in pain relief, a profound investigation method or an alternative mechanism are therefore required to validate the mechanism of KT.

1.2.3.2 Can Kinesio-taping alter activation – muscle activation

The discussion of the effect of KT (section 1.2.2.3) showed that KT is likely to have a small beneficial effect on muscle strength. It is therefore important to understand what the actual mechanism is. Analysis of electromyography data is a widely used method to monitor muscle activation. Słupik et al. (2007) reported a 10% change in muscle activity had previously been considered as smallest meaningful difference, based on the known typical error associated with measurement, however, the majority of differences in this study were unclear. Hsu et al. (2009) reported increased lower trapezius EMG amplitude during 60-to-30° of lowering phase of an arm elevation task, which aimed to assess the scapular plane, with KT applied

when compared with the placebo taping condition. Lee et al. (2012) reported significant reductions of maximal voluntary contraction EMG in vastus medialis oblique and vastus lateralis muscles in patients with patellofemoral pain syndrome when they received KT applications.

Even though a degree of EMG change after receiving KT application has been suggested, what magnitude and direction of change in muscle activation may represent a beneficial result is uncertain. An increase in muscle activation may indicate a facilitation effect, which is potentially enhancing muscle function. While a decrease in muscle activity could indicate KT is having a supporting effect and allowing muscles to work more efficiently and improve muscle endurance. The key concern should be what the goal of treatment is, which also depends on other factors such as the specific muscle being assessed, the purpose of the treatment, the characteristics of the selected subjects, and the taping technique.

Using Flexion-Relaxation (FR) phenomenon, which refers to a sudden onset of EMG silence in para-spinal muscles when the subjects reach the end of ROM during standing forward lumbar flexion (Callaghan and Dunk, 2002), as an index would be more straightforward than extracting confounding variables from muscle activation signals, as the analysis focus shifts form comparing activation level or EMG amplitude to EMG pattern changes. Examination of FR phenomenon would be a good index to investigate muscle function in patients with LBP as patients with LBP usually fail to achieve FR (Watson et al., 1997). Paoloni et al. (2011) compared KT, exercise and combined treatments in a group of LBP patients, who fail to achieve FR, and normalised FR was observed in 28.2 percent of all patients after treatment. However, no significant difference between KT in adjunct with exercise, KT and exercise on its own was found in this study. Further research is still needed in this area to clarify the linkage between the effects and mechanisms of KT application.

One proposed mechanism of muscle strengthening is that the concentric tension from KT may affect the fascia tension which may alter muscle contractions by changing the muscle activation patterns. As increased fascial stiffness would be expected to result in many muscular responses stimulated by fascial mechanoreceptors, for example, shifting activation thresholds (Schleip et al., 2005). An experiment in cats has shown a similar result that a temporary decrease of ligament stiffness resulted in the stimulation of fewer ligamentous mechanoreceptors and decreased muscle activation (Solomonow et al., 1999). In order to validate this hypothesis, links between KT, fascial stiffness and muscle activations are required. Therefore, more evidence to prove that KT can change biomechanical properties

of soft tissue, particular in fascia is desirable as well as the evidence indicating the correlation between fascia stiffness and EMG activations. At present, little evidence indicates that KT may influence muscle activation in some way. Threfore, more studies approaching soft tissue and muscle mechanisms biomechanically are required to clarify if wearing KT can actually influence the kinesiology.

1.2.4 Evidence conclusions

In summary, the situation with reviews of KT is less clear, and the evidence seems to be immature to enhance clinically meaningful directions. Six systematic reviews on overall effectiveness (Kalron and Bar-Sela, 2013, Lim and Tay, 2015, Morris et al., 2013, Mostafavifar et al., 2012, Parreira et al., 2014a, Williams et al., 2012), and two systematic reviews specifically focused on LBP (Nelson, 2016, Vargas Batista et al., 2014) found little in the way of consistent effects except on short-term pain and range of movement, but not enough to link the effect to clinical application. One of these reviews even concluded that KT applications do not currently have clinical importance Parreira et al. (2014a). Thus, it warranted more evidence discovery on either its actual mechanism or identifying if there are certain types of patients who can benefit from receiving KT treatments.

There are however some possibilities to determine subgroups of LBP patients, as some effects were observed in some studies (Al-Shareef et al., 2016, Castro-Sánchez et al., 2012, Kelle et al., 2016). The context of designing and delivering a treatment approach is valuable, but some limitations exist in previous studies. For example, Taping techniques in scientific studies were typically applied in a standardised fashion to keep consistency with typical research methods; and a few studies recruited asymptomatic subjects rather than patients, therefore limiting external validity. Furthermore, studies reported beneficial results using KT, but few studies have been investigating the actual mechanism of KT application. As mentioned, assessment of mechanisms alongside proposed theory is rather critical to decide if the hypotheses of KT application should be accepted. It is unlikely that evidence synthesis will be able to fully reveal the place of such approaches in the clinical armamentarium. Therefore, more mechanistic and sub-group studies are desired to address the absence of evidence, albeit having to accept the null hypothesis of no effect at present.

1.3 Overview of lower back pain

LBP is the single most common and troublesome musculoskeletal disorder (Shiri et al., 2008). The cause of back pain remains unclear in over 80 percent of the cases, even though there are some common spinal disorders related to LBP has been defined (Videman and Battié,

2012). Currently, no clear evidence indicated a treatment of choice due to its complex cause. Clinicians are therefore lacking guidance for making decisions about choosing tools for LBP treatment.

LBP is a common condition, and it can occur in any population regardless age. I found six systematic reviews on the epidemiology of LBP (Balague et al., 1999, Bressler et al., 1999, Ebbehøj et al., 2002, Hestbaek et al., 2003, Pengel et al., 2003, Walker, 2000). Two reviews specifically focused on children (Balague et al., 1999) and one on the elder generations (Bressler et al., 1999). None of these articles gave specific prevalence for acute, recurrent, chronic, or nonspecific LBP. It can be difficult to distinguish acute and chronic LBP due to a high number of recurrences and variability. There is a lack of standards for severity, location, and comorbid injuries. Walker (2000) categorised thirty out of fifty population prevalence studies of LBP, which were of acceptable quality, pointing out the prevalence of LBP ranged from 12-33%, 1-year prevalence from 22-65% and lifetime prevalence from 11-84%. Bressler et al. (1999) included 12 studies that specifically examined the prevalence of back pain in the elderly, which were defined by older than 65 years old, and concluded an uncertain prevalence, therefore, was not comparable with that in the younger population.

Two reviews reported a prevalence approaching and associated factors of LBP in children and adolescents (Balague et al., 1999, Ebbehøj et al., 2002). The cumulative (lifetime) prevalence was between 30% and 51% for subjectively rated morbidity and 14%-43% for objectively rated morbidity. The average annual incidence of LBP was estimated to be approximately 16%, with 50% of cases reporting recurrence, and 8% a chronic evolution (Balague et al., 1999).

LBP fluctuates over time with frequent recurrences or exacerbations. Two systematic reviews reported on the prognosis, long-term course or epidemiology of LBP, one included 36 studies (Hestbaek et al., 2003) and another included 15 studies (Pengel et al., 2003). Hestbaek et al. (2003) reported that, after the first episode of LBP, the proportion of patients who still experienced pain after 12 months was on average 62% (range 42-75%), the percentage of patients sick-listed after 6 months was 16% (range 3-40%), the percentage who experienced relapses of pain was 60% (range 44-78%), and the percentage who had relapses of work absence was 33% (range 26-37%). The other review concluded that rapid improvements in pain (mean reduction 58% of initial scores), disability (58%), and return to work (82% of those initially off work) occurred in the first month after an initial episode of LBP. Further improvement was apparent until about three months. After that levels of pain,

disability, and return to work remained almost constant. 73% of patients had at least one recurrence within 12 months (Pengel et al., 2003).

It is clear that LBP is an extremely common problem, which most people experience at some point in their life. Most cases run a chronic–episodic course. It has a huge impact on individuals, families, communities, governments and businesses throughout the world. Although current clinical practice guidelines - *European guidelines for the management of acute nonspecific LBP in primary care* recommend several treatments for LBP, most randomised controlled trials have shown that these treatments provide only mild to moderate clinical improvement in LBP patients (Van Tulder et al., 2006).The same guidelines also state that no difference has been proved between the various modalities of exercise-based therapy as well as manual therapy techniques. We, therefore, need better treatments. KT has been evaluated as a possible adjunct treatment. By adjunct, I mean a facilitator of treatments with longer-term effect. Further research is needed to help us understand more about the subgroups of LBP patients. For example, to identify whether there is a specific type of patients who are more likely to benefit from receiving KT therapy. This investigation can potentially help us to improve the current LBP care.

1.4 Why study of the thoracolumbar fascia is relevant to LBP

1.4.1 Structure and the biomechanical role of thoracolumbar fascia

This section provides a brief overview of gross anatomy of thoracolumbar fascia, and is trying to use a functional anatomical approach to link LBP with this particular tissue, as mechanisms of body function are usually overlooked and misleading in approaches using of categories such as spine and pelvis when discussing conditions like LBP (Vleeming et al., 1995). The functional anatomical approach, which is strongly linked to biomechanics, attempts to explain how bones, ligaments, muscles even skins operate as a system during particular movements of motions. This approach is, therefore, particularly relevant in the discussion of the effects and mechanisms of KT in the management of LBP.

To start from the surface of thoracolumbar area, skin, subcutaneous tissue, fascia and back muscles are usually categorised separately in descriptive anatomy (Martini and Bartholomew, 2001). However, all these structures are acting together as ‘bridge’ in connection with trunk, pelvis and lower limbs. Thoracolumbar fascia, therefore, transmits tension form these ‘anatomical relations’ during the movements. Among this, the thoracolumbar fascia, which has a multi-layer structure containing three directions of fibres, can transmit forces as a junction (Loukas et al., 2008). Connective tissue in the thoracolumbar area started to receive

attention in back pain studies due to its wide biomechanical connections across upper limbs, trunk towards to pelvic griddle (Willard et al., 2012). However, what biomechanics role the thoracolumbar fascia plays has yet been concluded despite the well-developed knowledge of its structure and connections (Loukas et al., 2008). To understand this fully, ultrasound assessments in the present PhD were used to discover the in-vivo behaviour of soft tissues within the thoracolumbar area during movements as a secondary aim.

1.4.2 Thoracolumbar fascia and Lower back pain

Connective tissues overlaying the back, particularly the thoracolumbar fascia are structures that may play an important role in preventing, causing or treating back pain (Schleip et al., 2007). Validation of this hypothesis should be started with the discussion of whether muscles or fascia contribute more to pain sensation. Tesarz et al. (2011) reported that the TLF possesses a dense network of nerve fibres including nociceptive units. They found that most sensory fibres are located in the outer layer of the fascia and the subcutaneous tissue, which are also considered as superficial fascia. These findings may reveal that thoracolumbar is an important source for LBP; this also explains that manual therapies directed at the fascia and the subcutaneous tissue, such as fascial release are often painful. However, knowing fascia is more sensitive than muscle is not enough to promise the responsibility of fascia for local pains. A study demonstrated increased pain in response to hypertonic saline injection directed to fascial tissue as compared with deep muscle injections following eccentric exercise, which is considered related with delayed onset muscle soreness (Gibson et al., 2009). The lack of increased pain response following deep muscle injection suggests that tissue specificity is important in the pain perception associated with delayed onset muscle soreness perception. In other words, Gibson's study suggested 'muscle soreness' is more closely associated with the increased sensitivity of fascia rather than muscle. A later study confirmed this inference by investigating electrical pain threshold of fascia and muscle after initial and secondary bouts of elbow flexor eccentric exercise (Lau et al., 2015).

Two observational studies provided actual links between thoracolumbar fascia and LBP. Langevin et al. (2009) found altered and thickened thoracolumbar myofascial structure at the second and third level of lumbar intervertebral disk region via ultrasound image assessment in participants with LPB. The same research team also reported that the thoracolumbar fascia shear strain, which is computed from the cine-ultrasound image, was reduced in patients with LBP compared with those without (Langevin et al., 2011). Neither the causative mechanisms underlying these changes nor the relationship to the symptoms is

clear. However, these findings have potential to provide a direction to discover a new approach in the treatment of LBP and are worthy of further exploration.

One clinical study indicated that functional fascial taping using solid tapes successfully reduced the worst pain in subjects with non-acute non-specific LBP within 2-weeks period clinical trial (Chen et al., 2012). This study provided a potential positive result to link fascial intervention and LBP treatment. However, no direct evidence revealing the actual mechanism of taping has been demonstrated in this study. This is a similar concern with the other KT studies. A later published study reported that the same type of taping technique affected muscle stiffness at rest and during contraction (Hug et al., 2014). This mechanism study promised a further potential to discover more taping mechanisms. Although a different tape type and technique was used in these studies, results indicated that it is possible to alter tissue biomechanical characteristics by surface interventions such as taping. The present project was, therefore, aiming to discover evidence demonstrating the association between KT treatment and soft tissue parameters.

1.5 Summary of current evidence and focus of the thesis

This chapter has firstly examined the effectiveness and potential mechanism of KT in a broad range of applications and identified that KT might have small effects for some particular treatment purposes. For example, KT can be applied for a short-term pain relief (Kelle et al., 2016, Kaplan et al., 2016). However, current evidence seems to be trivial when considering the clinical importance of KT due to the lack of understanding of the actual mechanism of KT applications. Despite the inventor and many other manufacturers claimed different mechanisms, such as KT relieving pain by lifting sub-cutaneous tissue; KT could alter muscle activation and proprioception via the stimulation of taping tension, no high-quality studies with direct evidence are available to validate these proposed mechanisms to date. Therefore, a better approach to discover robust information to help to either improve this treatment method or give up this intervention is required. The main reason for seeking a better treatment method is because current treatment for LBP care does not have successful outcomes. Literature discussed in this chapter also identified the connective tissue in the thoracolumbar area to be a potential therapeutic target, and taping is likely to be a way to alter soft-tissue biomechanics and then achieve a defined treatment purpose. However, current evidence is not enough to validate these hypotheses. This PhD project was intended to contribute to this process by conducting an LBP focused systematic review to examine the effectiveness of KT in LBP care on its own or as an adjunct therapy; developing a robust assessment method to discover the links between LBP pathology, connective tissue

biomechanics and KT applications; and finally to perform controlled observational studies in people with and without LBP. Ultimately this work can inform clinicians about potential future directions in acute LBP care.

Apart from contribution to LBP care, this PhD project has the additional potential to contribute to soft tissue related research fields. A new ultrasound-based method for dynamical soft tissue analysis during movements showing its reliability and validity in the development of the methodology was completed. This is a new approach for examining KT mechanisms but not limited to taping therapy. It is a transferable tool for studies of other therapeutic techniques, particularly, those alternative treatment methods which are being used without a clear understanding of their mechanism and actual effects.

CHAPTER 2 AIMS AND OBJECTIVES

2.1 Overall aim

The overarching aim of this thesis was to determine whether biomechanical tissue responses could be identified and then used to determine subgroups of responders or non-responders to KT. The primary objective was to investigate whether KT can alter soft tissue and body biomechanics, such as segment movements, muscle activation, tissue deformation and tissue properties. This required detailed methodological developments. The secondary goal was to apply these methods and compare the tissue behaviour in participants with back pain and those without in order to identify sub-groups. The impact of success would be the information required to plan selective targeting of interventions.

2.2 Aims, corresponding objectives and alternative hypotheses (H_1)

1. **Aim: To summarise the current evidence related to KT application in the treatment of LBP.** This was performed to aid the identification of gaps in the current literature and guide the direction of the observation studies within the thesis.

   Objective: To complete an LBP focused systematic review and meta-analysis of the current literature. Clinical outcomes, such as self-report pain scale and disability scale, after receiving treatment of KT were collated from included journal articles and compared to other physiotherapies – *see Chapter 3*.

2. **Aim: To develop a reliable in vivo measurement technique to enable exploration of taping mechanisms.** This tool enabled an innovative approach in examining the effect of KT.

   Objective: A semi-automatic three-dimensional method of ultrasound-based tissue movement tracking was developed with supervision. This method has been tested with two types of phantoms and human participants to ensure its consistency and validity *see – Chapter 4.4.1*

H_1: The developed method and imaging procedure could reproduce consistent measurement results from both phantoms and human bodies without systematic errors.

H_1: There would be a consistent difference between measurement performed with the developed ultrasound method and validated motion capture system.

3. **Aim: To examine the effect of KT application on the thoracolumbar fascia in asymptomatic participants using a newly developed ultrasound tool.** This exploration could provide a better understanding of how the thoracolumbar soft tissue responds to KT and provide a tool for subsequent observations in people with LBP.

   Objective: To measure changes in biomechanical parameters of soft tissue after receiving KT applications. Soft tissue movement data in the thoracolumbar area, lumbar range of motion and para-spinal muscle activation when performing the lumbar flexion task with and without KT were captured for comparisons – *see Chapter 5.1.*

   H_1: There would be consistent changes in sagittal tissue movement pattern present when participants performed the designated movement after KT application.

   H_1: There would be consistent changes in muscle activation when participants performed the designated movement after KT application.

4. **Aim: To investigate the effect of K-tape on thoracolumbar stiffness and deformation during lumbar flexion,** in order to inform efforts to understand taping mechanisms and ultimately target treatment better.

   Objective: To measure tissue stiffness in various layers using ultrasound shear-wave imaging of the thoracolumbar area. These would include sub-cutaneous and fascial zones when participants adopted three related lumbar flexion postures with and without KT – *see Chapter 5.2.*

   H_1: Applying KT would change shear wave velocity of thoracolumbar tissue including subcutaneous tissue and fascia present in asymptomatic participants.

5. **Aim: To explore how KT would affect tissue movements during different movement tasks in people with LBP**. This exploration was carried out to meet the aim above and provide key information for further sub-grouping identification.

Objective: To measure soft tissue movement in the thoracolumbar area and lumbar range of motion when performing the lumbar flexion task both with and without KT. Participants were performing the lumbar flexion task in multiple conditions, such as increasing / reducing loads, or changing posture with and without KT – *see Chapter 6*

H_1: There would be consistent changes in sagittal tissue movement pattern present when participants with LBP perform the designated movements after KT application.

H_1: Sagittal tissue movement would respond to KT in a consistently different way compared to asymptomatic participants.

6. **Aim: To discover whether relevant sub-groups of people with LBP could be identified.** Ultimately this exploration could inform us whether to discard KT from treatment options or to develop this kind of treatment further according to the biomechanical indicators found in the sub-group exploration.

   Objective: To compare whether people, who immediately responded to KT applications, have different soft tissue reactions from those who did not respond.

   H_1: There would be demonstrable differences in sagittal tissue movement patterns between KT responders and non-responders.

CHAPTER 3 SYSTEMATIC REVIEW

Clinical relevance of Kinesio-Taping to LBP care

3.1 Background

Nonspecific LBP typically presents with pain that is not readily associated with a recognisable diagnostic label, places a significant socioeconomic burden upon the healthcare system and is a major cause of work disability (Martin et al., 2008, Manchikanti et al., 2009). This is a common issue within the population, as it is currently estimated that 70-80% of the population will experience some form of LBP within their lifespan (Walker et al., 2004). Acute LBP usually subsides within the first six weeks, and a rapid reduction in pain and disability score are usually expected after the first week (Costa et al., 2012). Failure of resolution of this pain within six weeks is associated with longer-term disability, with interventions typically proving less effective (Costa et al., 2012). There are numerous conservative treatments available for LBP, including education programs (Engers et al., 2008), manual therapy (Rubinstein et al., 2012), exercise (Hayden et al., 2012), electro-physical agents (Khadilkar et al., 2008) and medication (Roelofs et al., 2008, Chaparro et al.). Previous research into the effectiveness of these treatments has noted mixed results with a moderate effect at best (Airaksinen et al., 2006).Therefore, research into other interventions, which may augment clinical and cost-effectiveness, is needed (Delitto et al., 2012).

KT was developed in the 1970s and has widespread use for numerous conditions (Kase et al., 2003), one proposed use is for patients suffering from LBP. The design of the tape, being thin and light and relatively less restrictive of the ROM (Kase et al., 2003), may make it a useful intervention to help reduce the duration and severity of painful episodes and therefore reduce absence from work due to LBP. It has been proposed that KT can be used as an additional treatment to expend and maintain the effect of usual care (Kase et al., 2003). As mentioned in Chapter 1, it has been claimed that KT decreases pain by the following mechanisms: improving blood and lymphatic flow in areas of inflammation, elevating the skin to reduce pressure on mechanoreceptors below the dermis and altered muscle recruitment through excitatory and inhibitory neuromuscular mechanisms. It should be

noted that all these guidelines, including which conditions this tape may be beneficial for, as well as the proposed mechanisms, were suggested by the developer of the tape and therefore require research into effectiveness. However, there is yet a universal guideline for application techniques or a body of evidence to support the effectiveness of this therapy.

Past research has shown KT to typically result in poor clinical outcomes for both pain and disability (Kalron and Bar-Sela, 2013, Morris et al., 2013, Mostafavifar et al., 2012, Parreira et al., 2014a, Williams et al., 2012). However, it should be noted that this was performed for a number of conditions rather than focused on LBP care. The aforementioned systematic reviews reviewed the effectiveness of KT when applied to multiple conditions, such as; patellofemoral pain syndrome, neck pain, sub-acromial impingement syndrome, rotator cuff tendonitis/impingement and plantar fasciitis (Parreira et al., 2014a). To date, there has been no systematic review with meta-analysis into the effectiveness of KT on LBP specifically. A lack of understanding of the mechanism of action of the tape suggests that combining multiple conditions, which may have different pathophysiological causes, may not produce results which are truly representative of the intervention's clinical applicability. In other words, the effects may be obscured or confounded by sample heterogeneity.

Therefore, this systematic review aimed to summarise the current evidence related to KT application in the treatment of LBP. The objective was, therefore, to complete an LBP focused systematic review and meta-analysis of the current literature to assess whether KT provides any significant changes in pain or disability among patients with nonspecific LBP; both as an independent intervention or as an adjunct to other therapy. This review highlighted the need for future research into the clinical applicability of KT among other conditions and further research into its mechanism of action. This was performed to aid the identification of gaps in the current literature and guide the focus of subsequent observational studies which are mechanism focused rather than investigating intervention effectiveness.

3.2 Methodology

3.2.1 Search Strategy

PubMed, Web of Science, the Cochrane Library, Scopus, and EMBASE were searched from inception to 1 December 2015. The initial search was not limited by language or subject species in order to allow an estimation of possibly relevant research conducted which have

not been analysed due to not being published in English. However, foreign publications without English title and abstract were not able to be tracked.

Search terms were inputted into databases by choosing the keywords "kinesio taping" and "low back pain". The incorporation of BOOLEAN operators was used to help ensure an accurate and broad assessment of databases. This included the use of "OR" to find synonyms which may have been used by other authors and "AND" to ensure that the papers found were more likely to be specific to the question. A list of terms and operators used is listed:

(lumbar pain OR thoracolumbar pain OR thoraco-lumbar pain OR low back pain OR chronic low back pain OR lower back pain OR chronic lower back pain OR LBP OR back pain OR nonspecific OR non-specific)

AND

(kinesiotaping OR kinesio taping OR kinesio tape OR kinesiotape OR kinaesthetic taping)

3.2.2 Review process

All retrieved papers were downloaded and imported into Endnote X7.0.1 (Bld 7212). Duplicate papers were removed, and titles screened, with all obviously non-relevant studies excluded. Once this had been completed, the more detailed assessment was applied to the studies ensuring that the final studies were relevant to the stated inclusion criteria (Box 1). It should be noted, that papers with varying taping techniques or duration of therapy were not excluded. Final papers were inputted into Google Scholar for citation tracking to help identify additional relevant studies not located during initial searches.

Quality assessment

The PEDro scale was applied to the final results of the literature search, the randomised control trials (RCTs) retained for further analysis (Maher et al., 2003). These studies were independently assessed by two reviewers. The eleven-item scale was applied to each of the studies and scores compared between assessors. One of these criteria is not routinely included in quality assessments, producing a score out of 10. If any discrepancies were present, the two reviewers met and discussed the result until consensus was reached. Studies with a score higher than 5 out of 10 (exclusive) were considered as high-quality (HQ) papers and scores lower than 5 out of ten (inclusive) were considered as low-quality (LQ).

Data extraction

In order to identify which papers qualified for assessment by meta-analysis, data was extracted from final results of the literature search. Information such as control/interventions and their protocols, outcome measures used to assess and taping technique were included in Box 2. From these, papers were identified for pooling and analysis of subclasses was permitted. Means and standard deviations were extracted from papers effect sizes expressed using Cohen's d, (ES) calculated with Cochrane Review Manager (ver5.3.5, The Cochrane Collaboration, Copenhagen, Denmark). Effect sizes were categorised as either small (0.2-0.3), medium (~0.5) or large (>0.8), as suggested by Cohen's criteria (Cohen, 1992, Rosenthal et al., 1994). The strength of evidence supporting the objectives examined in this paper was determined by the criteria proposed by *Van Tulder et al. (2003)* (Box2).

Box 1. Inclusion and Exclusion Criteria

Inclusion Criteria:

- Design: Randomised control trials, control group present
- Participants: Any adult human (>18years of age), back pain >4 weeks, no other spinal pathology, no nervous system conditions, not pregnant or pregnancy related.
- Intervention: Kinesio tape or other trademark names, any application technique, any duration of therapy.
- Outcome measures: Pain intensity (Visual Analogue Scale), and disability score (Roland Morris Disability Questionnaire (RMDQ), Quebec Functional Disability Questionnaire or Oswestry Low Back Disability Index(ODI))

Exclusion criteria:

- Design: Patents, non-RCTs, Dissertations, Theses
- Participants: Non-human, children (<18 years of age), presence of any spinal pathology, presence of any nervous system condition, pregnant or pregnancy related pain
- Intervention: other forms of taping which are not Kinesio-tape

Box 2. Strength of evidence summary *(Van Tulder et al., 2003)*

- ***Strong evidence***
  Provided by statistically significant findings in outcome measures in at least 2 high- quality (HQ) RCTs with PEDro scores of at least 4 points
- ***Moderate evidence***
  Provided by statistically significant findings in outcome measures in at least 2 HQ studies which are heterogeneous, at least one HQ study and LQ study or multiple LQ studies which are homogenous
- ***Limited evidence***
  Provided by statistically significant findings in outcome measures in multiple heterogeneous LQ studies or one HQ study
- ***Very limited evidence***
  Provided by statistically significant findings in outcome measures in LQ study
- ***Conflicting evidence***
  Insignificant results from multiple pooled studies, regardless of statistical heterogeneity or homogeneity.

3.3 Results

3.3.1 Results of literature search

The initial search produced 665 citations, upon removal of duplicates, titles were screened leaving a total of 193 papers. The following results were screened in detail and resulted in 8 papers. The reasons for exclusion of these papers included: not related to low back, outcome measures were not as those specified in inclusion and exclusion criteria, inability to access full paper in English, unable to extract mean values, taping method was not KT, signs of other pathology responsible for LBP and not randomised control trials (Figure 4). Two papers did meet all requirements for inclusion in this study (Asthana et al., 2013, Adamczyk et al., 2008), but exact mean values and SDs could not be attained. Therefore, these studies was excluded from the meta-analysis. Results of quality assessment, by PEDro (Physiotherapy Evidence Database) scale, taping technique and greater detail of included studies are provided in

Table 1.

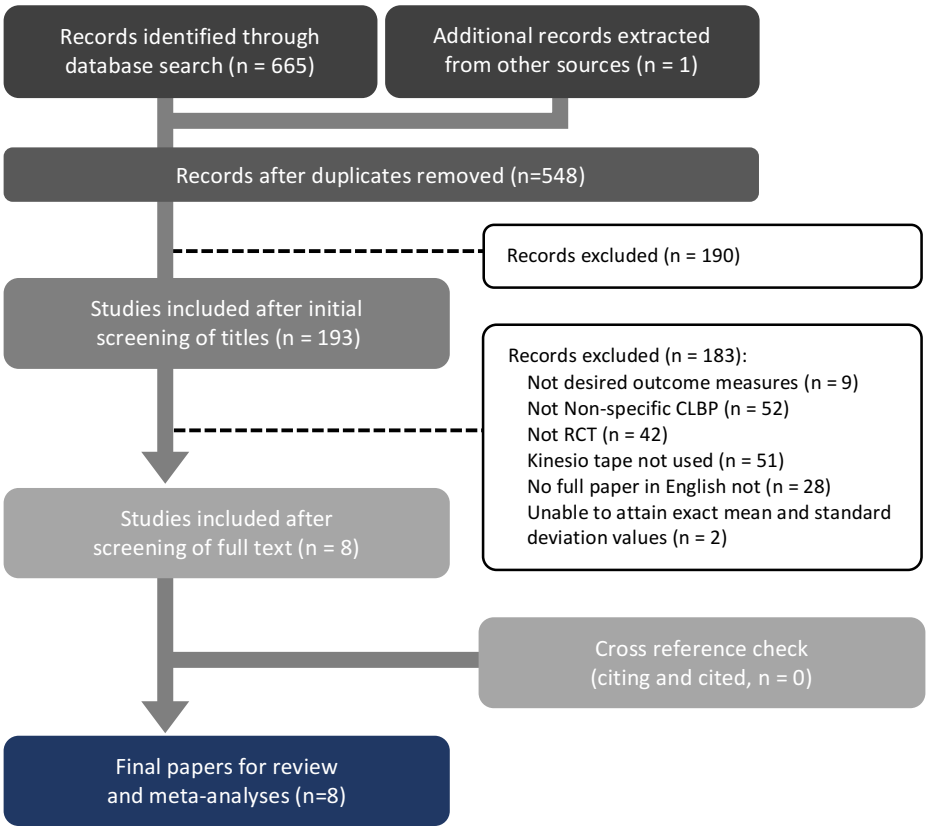


Figure 4. A flow diagram illustrating the literature search performed, displaying numbers of results excluded and the corresponding reason for exclusion.

3.3.2 Effects on Pain Scores

The findings from the meta-analysis of VAS scores showed no statistically significant results (see Figure 5; SMD (CI) = -0.28 (-0.76 to 0.21); ES = 1.12, p = 0.26), when looking at the overall effect of seven of the studies. The study by Yousefpour et al. (2013) was excluded due to not using VAS or comparable pain scores as an outcome measure.

For the purposes of more in depth analysis the pooled studies were separated into subgroups to allow more accurate analysis. As an adjunct to conventional therapy, KT was not statistically significant better than controls (SMD (CI) = -0.34 (-1.76 to 1.08); ES = 0.47, p = 0.64). On comparison of KT to sham taping, there were also no significant difference (SMD (CI) = -0.28 (-0.63 to 0.06); ES = 1.62, p = 0.11). There were no statistically significant differences when comparing KT therapy to exercise therapies, neither. (SMD (CI) = -0.30 (-0.86 to 0.26); ES = 1.04, p = 0.30).

3.3.3 Effects on Disability Score

Forest plots were formulated to allow pooling, for various outcome measures. For this review, three outcome measures for disability were included. These were separated into two forest

plots. One forest plot did not pool data between subgroups; this meant analysis of the papers for ODI and the Quebec could also be analysed (Figure 6). The Second Forest plot allowed subgroup analysis with pooling included (Figure 7). This allowed comparisons between modalities KT be compared against.

The findings suggested that KT had no statistically significant effects at reducing disability scores, for ODI (SMD (CI) = -0.16 (-0.58 to 0.26); ES = 0.76, p = 0.45) or QBDS (SMD (CI) = -0.01 (-0.55 to 0.53); ES = 0.04, p = 0.97), post intervention. Pooled analysis of six studies, which used RMDQ as an outcome measure, suggested that KT therapy was significantly less effective when compared to other modalities (SMD (CI) = 0.30 (0.04 to 0.56); ES = 2.25, p = 0.02). This was stratified for subgroup analysis. There was a statistically significant result which suggested conventional therapy is more effective at reducing disability score, when compared to adding KT as an adjunct (SMD (CI) = 0.62 (0.13 to 1.12); ES = 2.45, p = 0.01). However, there were no difference when comparing KT to sham taping (SMD (CI) = 0.17 (-0.08 to 0.42); ES = 1.35, p = 0.18) or exercise therapy (SMD (CI) = 0.11 (-1.32 to 1.54); ES = 0.15, p = 0.88).

Table 1. Summary of the final papers included in final analysis

Study	Participants	Intervention / control group	Taping technique and duration	Outcome measure and results	Quality
Bae et al. (2013)	• 20 patients with chronic LBP (duration >12 weeks and no other lumbar pathology or skin sensitivity to tape and had a VAS and ODI score of 6 and higher.) • Age: control 51.3 ± 3.7; experimental group 53.6 ± 2.1	• 2 groups (n=10): KT, control • Randomisation: envelopes. • Both groups received a hot pack, physical therapy, US and transcutaneous electrical nerve stimulation 3 times a week.	• Taping procedure for control used inelastic "I" band transversely along the back. Experimental group used 4 "I" strips in a star shape • 12-week programme	• Pain: VAS 0-100mm • Disability: ODI • a significant decrease in both pain and disability within experimental and control groups ($p<0.05$) • The greatest difference between groups: significant effect in disability among the experimental group ($p<0.01$)	Low Quality (5 /10)
Luz Júnior et al. (2015)	• 60 patients with CLBP (>12 weeks) • Aged 18-80	• 3 groups: KT(n=20) micro-taping(n=20) no tape (n=20)	• Taping technique involved • placement of paravertebral bilateral "I" bands from the PSIS to T8 • Patient assessed at 48 hours and 7days (the final endpoint's results were analysed)	• Pain: VAS 0-100mm • Disability: RMDQ • A significant difference between KT and micro-taping at 48 hours post interventions. Not deemed clinically worthwhile.	High Quality (8 /10)
Castro-Sánchez et al. (2012)	• 60patients with chronic LBP • defined as duration >3 months) • Must score >3 on RMDQ • Age range18-65 intervention 50 ± 15, control 47 ± 13	• Randomisation: envelopes picked up by independent investigator (blinded) • Patients blinded	• KT group: received 4 KT strips at 25% tension in a star shape • Control: sham tape consisting of single horizontal strip of "I" band tape • Recorded at 7 days and 5weeks only reported results analysed from the endpoint at 5weeks	• End of week 1 the intervention group had a significant improvement in the ODI, 4-point decrease (95% CI 2-6) and RMQD, 1.2 decreases (CI 0.4-2). NOT significant at the end of 4 weeks • A significant decrease in pain, VAS, compared to control. mean difference 1.1cm (CI 0.3-1.9), immediately after tape applied and remained significant at 4 weeks 1cm (CI 0.2-1.7)	High Quality (9/10)
González Enciso (2009)	• 14 patients, 8 completed protocol. • Age range 20-50. KT group: 40.5, Exercise group 38.4. • chronic back pain sufferer > 4 weeks	• Randomisation: Office secretary picked sealed envelopes • Exercise group followed Garcia et al. protocol and posture adaptations • No mention of Kinesio-tape technique details	• KT applied as paravertebral bilateral I bands • Results were retrieved 15-21 days after application	• Disability measure only • No significant difference in the disability score: Quebec +1 point (p=0.77), Oswestry +3 (p=0.60), Roland -1(p=0.70)	High Quality (6 /10)

Table 1. Summary of the final papers included in final analysis (continued)

Study	Participants	Intervention / control group	Taping technique and duration	Outcome measure and results	Quality
Kachanathu et al. (2014)	• 40 participants (30 men, 10 women) • Age 34.8 ± 7.54	• Group: Conventional exercise + KT; Conventional therapy only • Duration: 4weeks	• KT: 2 'I' band strips paravertebrally over erector spinae, for 4 weeks	• OM: pain VAS and 24 item RMDQ • Significant improvement in pain and disability in Group 1. • No difference between groups in pain and disability.	Low Quality (3 /10)
Paoloni et al. (2011)	• 39 participants, age: 30-38 (34.8 ± 7.54) • Back pain > 12weeks	• Randomised groups by computer sequence. • Group: KT, exercise, KT + exercise. • Duration: 4weeks	• KT: 3 'I' bands between T12 and L5, paravertebrally and over the vertebra • Duration: 4 weeks	• Pain: VAS 0-100mm • Disability: 24 item RMDQ • Significant pain decreases in all groups • Disability scale decreases in exercise group only.	High Quality (7 /10)
Parreira et al. (2014b)	• 148 LBP participants • Age: 18-80	• Group: KT following Kase's guidelines; KT with higher tension. • Duration: 4 weeks (twice per week)	• Assessed at the end of 4 weeks and 12 weeks after application • Bilateral paravertebral 'I' band application	• Both groups had decreased VAS and RMDQ • No difference between groups found	High Quality (9 /10)
Yousefpour et al. (2013)	• 39 participants (male) • Age: 47-69	• Groups: Pilates, KT, Pilates + KT • Duration: 6 weeks	• KT: 2 'I' bands paravertebrally with no stretch	• OM: Pain, VAS 0-100mm; Disability score (20-100) • Significant reduction in pain and disability in all group. • The most affected group were Pilates + KT • KT shows better result than Pilates (p=0.04)	Low Quality (4 /10)

OM= outcome measures; VAS= Visual Analogue Scale; ODI= Oswestry Low Back Disability Index; RMDQ= Roland Morris Disability Questionnaire;

Study or subgroup	Kinesio-Taping Mean	SD	Total	Controls Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CIU
KT as an adjunct to conventional therapy								
Bae et al.(2003)	5.70	0.78	10	5.14	0.95	10	10.00%	-0.08 [-0.95, 0.80]
Kachanathu et al. (2014)	6.00	1.80	20	3.70	2.00	20	11.50%	1.18 [0.51, 1.86]
Paoloni et al. (2011)	3.07	2.50	13	3.50	2.40	13	10.80%	0.08 [-0.69, 0.85]
Yousefpour et al. (2013)	1.91	0.66	13	3.75	0.62	12	8.10%	-2.78 [-3.92, -1.63]
Subtotal (95% CI)			**56**			**55**	**40.30%**	**-0.34 [-1.76, 1.08]**
Heterogeneity: Tau² = 1.90; Chi² = 34.10, df = 3 (P < 0.01); I² = 91%								
Test for overall effect: Z = 0.47 (P = 0.64)								
KT in comparison to sham taping								
Castro-Sánchez et al. (2012)	4.70	1.40	30	5.60	1.40	29	12.60%	-0.63 [-1.16, -0.11]
Luz Júnior et al. (2015)	5.80	1.30	20	6.30	2.00	20	11.90%	-0.29 [-0.91, 0.33]
Parreira et al. (2014b)	4.40	2.80	74	4.60	2.50	74	13.90%	-0.07 [-0.40, 0.25]
Subtotal (95% CI)			**124**			**123**	**38.40%**	**-0.28 [-0.63, 0.06]**
Heterogeneity: Tau² = 0.04; Chi² = 3.21, df = 2 (P = 0.20); I² = 38%								
Test for overall effect: Z = 1.62 (P = 0.11)								
KT in comparison to exercise								
Paoloni et al. (2011)	3.10	2.80	13	3.50	2.40	13	10.80%	-0.15 [-0.92, 0.62]
Yousefpour et al. (2013)	3.41	0.79	12	3.75	0.62	12	10.50%	-0.46 [-1.28, 0.35]
Subtotal (95% CI)			**25**			**25**	**21.20%**	**-0.30 [-0.86, 0.26]**
Heterogeneity: Tau² = 0.00; Chi² = 0.30, df = 1 (P = 0.58); I² = 0%								
Test for overall effect: Z = 1.04 (P = 0.30)								
Total (95% CI)			**205**			**203**	**100.00%**	**-0.28 [-0.76, 0.21]**
Heterogeneity: Tau² = 0.41; Chi² = 39.59, df = 8 (P < 0.01); I² = 80%								
Test for overall effect: Z = 1.12 (P = 0.26)								
Test for subgroup differences: Chi² = 0.01, df = 2 (P = 1.00), I² = 0%								

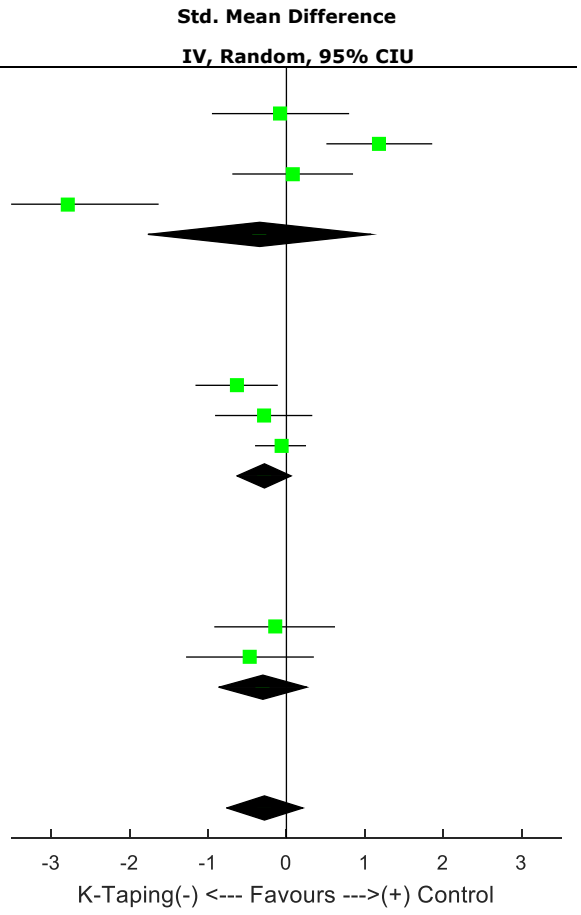


Figure 5. Forest plot showing the effects of Kinesio-taping on pain score, VAS

Study or subgroup	Kinesio-Taping Mean	SD	Total	Controls Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CIU
ODI								
Castro-Sánchez et al. (2012)	26.00	3.00	30	27.00	6.00	29	28.00%	-0.21 [-0.72, 0.30]
Bae et al.(2003)	10.75	4.73	10	11.34	3.32	10	17.30%	-0.14 [-1.02, 0.74]
González Enciso (2009)	24.75	7.90	4	29.25	14.20	4	9.20%	-0.34 [-1.75, 1.07]
Subtotal (95% CI)			**44**			**43**	**54.30%**	**-0.20 [-0.63, 0.22]**
Heterogeneity: Tau² = 0.00; Chi² = 0.06, df = 2 (P = 0.97); I² = 0%								
Test for overall effect: Z = 0.95 (P = 0.34)								
Quebec Back pain Disability Scale								
Yousefpour et al. (2013) as adjunct	35.25	11.49	13	44.08	9.56	12	18.60%	-0.80 [-1.63, 0.02]
Yousefpour et al. (2013) vs. Pilates	52.50	7.82	12	44.08	9.65	12	17.90%	0.93 [0.08, 1.78]
González Enciso (2009)	47.75	12.10	4	53.00	24.10	4	9.20%	-0.24 [-1.64, 1.16]
Subtotal (95% CI)			**29**			**28**	**45.70%**	**-0.03 [-1.19, 1.14]**
Heterogeneity: Tau² = 0.79; Chi² = 8.36, df = 2 (P = 0.02); I² = 76%								
Test for overall effect: Z = 0.04 (P = 0.97)								
Total (95% CI)			**73**			**71**	**100.00%**	**-0.12 [-0.60, 0.36]**
Heterogeneity: Chi² = 8.73, df = 5 (P = 0.12); I² = 43%								
Test for overall effect: Z = 0.49 (P = 0.63)								
Test for subgroup differences: Chi² = 0.08, df = 1 (P = 0.78), I² = 0%								

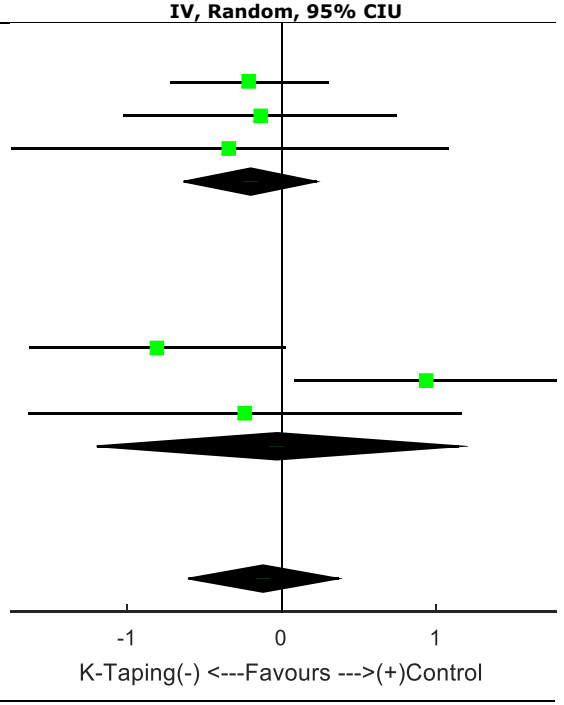


Figure 6. Forest Plot showing the effects of Kinesio-tape on the post intervention disability scores, ODI and QBDS

Study or subgroup	Kinesio-Taping Mean	SD	Total	Controls Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CIU
KT as an adjunct to conventional therapy								
Kachanathu et al. (2014)	10.80	5.00	20	7.00	5.50	20	13.20%	0.71 [0.07, 1.35]
Paoloni et al. (2011)	7.30	3.60	13	5.40	3.90	13	9.50%	0.49 [-0.29, 1.27]
Subtotal (95% CI)			**33**			**33**	**22.60%**	**0.62 [0.13, 1.12]**
Heterogeneity: Tau² = 0.00; Chi² = 0.18, df = 1 (P = 0.67); I² = 0%								
Test for overall effect: Z = 2.45 (P = 0.01)								
KT in comparison to sham taping								
Parreira et al. (2014)	8.30	6.90	74	7.40	6.40	74	33.10%	0.13 [-0.19, 0.46]
Castro-Sánchez et al. (2012)	9.80	2.20	30	8.60	3.00	29	18.30%	0.45 [-0.07, 0.97]
Luz Júnior et al. (2015)	9.60	5.60	20	10.20	7.40	20	13.90%	-0.09 [-0.71, 0.53]
Subtotal (95% CI)			**124**			**123**	**65.30%**	**0.17 [-0.08, 0.42]**
Heterogeneity: Tau² = 0.00; Chi² = 1.86, df = 2 (P = 0.40); I² = 0%								
Test for overall effect: Z = 1.35 (P = 0.18)								
KT in comparison to exercise								
Paoloni et al. (2011)	9.50	6.80	13	5.40	3.90	13	9.10%	0.72 [-0.08, 1.51]
González Enciso (2009)	9.50	6.10	4	14.75	5.80	4	2.90%	-0.77 [-2.25, 0.72]
Subtotal (95% CI)			**17**			**17**	**12.10%**	**0.11 [-1.32, 1.54]**
Heterogeneity: Tau² = 0.73; Chi² = 2.98, df = 1 (P = 0.08); I² = 66%								
Test for overall effect: Z = 0.15 (P = 0.88)								
Total (95% CI)			**174**			**173**	**100.00%**	**0.30 [0.04, 0.56]**
Heterogeneity: Tau² = 0.03; Chi² = 7.63, df = 6 (P = 0.27); I² = 21%								
Test for overall effect: Z = 2.25 (P = 0.02)								
Test for subgroup differences: Chi² = 2.55, df = 2 (P = 0.28), I² = 21.5%								

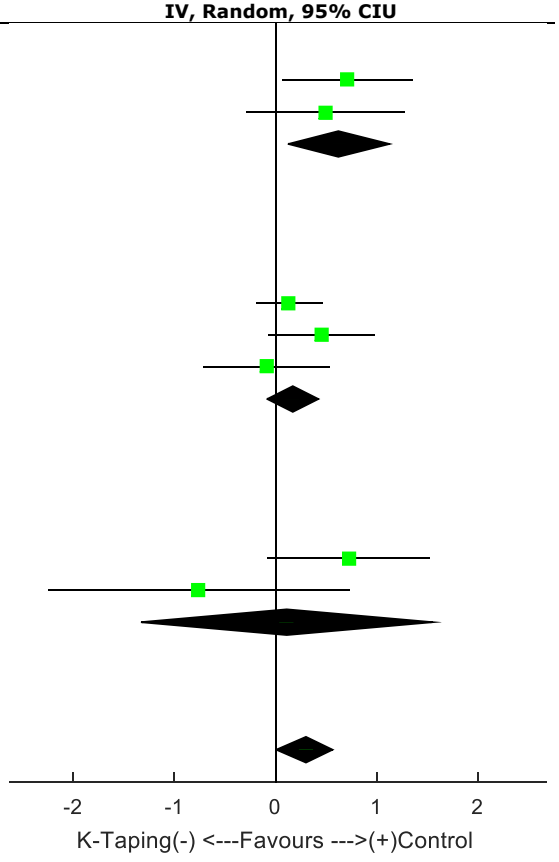


Figure 7. Forest Plot showing the effects of Kinesio-tape on the post intervention disability scores of the RMDQ. Subgroup analysis was performed to allow effectiveness comparison between Kinesio-tape and sham taping, exercise therapy and adjunct

3.4 Discussion

This systematic review and meta-analysis provided a clinically relevant summary of the effectiveness of KT as a therapy for the treatment of nonspecific chronic LBP, regarding reducing pain and disability in comparison to exercise therapy, sham taping and as an adjunct to conventional therapy. The results suggest KT has no overall effect on pain reduction in people with LBP, and very limited evidence suggested that KT is less effective in disability index improvement in LBP.

3.4.1 Main Findings

The results from this paper suggested that KT not be an effective method for reducing pain when used as an adjunct, in comparison to placebo or in comparison to exercise therapy. Upon subgroup analysis of isolated or combined treatment, the results were also found not to be significant. It should be noted that the papers were statistically heterogeneous due to different procedures and lengths of therapy being used in included studies (see Figure 5). Although this issue can be solved if further studies all follow similar guidelines during their methodological protocols, there is likely to be little value in conducting more effectiveness studies this way because LBP has such a heterogeneous nature. A robust guideline cannot be suggested until an understanding of mechanisms and identification and investigation of sub-groups are achieved.

A significant result suggested that other modalities of therapy, which did not incorporate KT therapy, were more effective at reducing RMDQ scores. In the subgroup analysis, it was found that conventional therapy without the use of KT as an adjunct was more effective at reducing RMDQ scores. According to Van Tulder's criteria (2003), it is suggested that there is very limited evidence supporting this finding. Therefore, whether the conventional therapy improves disability in patients with LBP patient is inconclusive. Clinicians and scientists need to determine better treatments or possibly identify other ways of prescribing treatment and therefore improve effectiveness.

3.4.2 Strengths and Limitations

This review provided a greater number of studies and meta-analysis compared to the previous papers published by Vargas Batista et al. (2014) and Nelson (2016), and sub-group comparisons of KT as an adjunct and in comparison to other modalities. These papers only include 3 to 5 papers, with some eligible articles not included because exact mean values and SDs could not be obtained. The inclusion of meta-analysis helps to improve the power underpinning conclusions reached (Haidich, 2010).

Papers were not subgrouped based on the duration of therapy, and all taping techniques were included to permit a greater number of papers to be included. These should be considered as causes of methodological heterogeneity when looking at the results of the meta-analysis. For example, several papers had multiple endpoints. Therefore, the effects of different lengths of therapy have to be ignored in this study. Methods of included papers are outlined in Table 1.

A particular limitation of this study was the consideration of heterogeneity between studies included for meta-analysis, and therefore caution should be taken when analysing these results. There were several differences methodologically between studies. One such example includes the variation of assessment period (see Table 1). The majority assessed results four weeks post-intervention, but studies conducted by Castro-Sánchez et al. (2012), *Yousefpour et al. (2013)* and Bae et al. (2013) had differing assessment points; 5, 6 and 12 weeks, respectively, post-intervention.

Heterogeneity was also increased due to the differences in taping technique (Table 1). Several studies follow Kase's technique of applying the KT with little tape tension but at the end of the available range of movement to allow the formation of convolutions within the tape on return to a neutral position, which is believed to cause folds in the skin. This is believed to elevate the skin above superficial receptors and help to reduce pain (Kase and Wallis, 2002). However, the amount of tension applied during the procedure is not mentioned within most of the studies. It is possible that all included studies used different KT applications. For example, two of the papers chose to use the star technique (Bae et al., 2013, Castro-Sánchez et al., 2012), where the multiple bands meet at the point of maximum pain. It should be noted that the paper by *Castro et al.* employed this application, and produced a significant reduction in VAS when compared to the sham taping. The other papers opted for "I band" strips placed paravertebrally over the insertion of the erector spinae muscles. Another notable cause of heterogeneity between papers was the lack of consistency between methods of sham taping. Luz Junior *et al.* compared KT to micro-taping and found no statistical differences. However, Parreira merely defined sham taping as a similar application, with tension applied when it should not be. The study by Castro-Sanchez *et al.* chose to apply the tape, not along the lines of the muscles and was the only one of these three papers to produce a statistically significant result. It is clear that further research is needed into which technique, if any, provides the greatest clinical efficacy. A new study by Lim and Tay (2015) has started addressing this gap in knowledge and will help guide studies in the future when comparing KT to placebo.

Another issue of importance which was only considered by some of the included studies was the use of analgesics. 3 of the papers did not specify the exclusion, or documented use of analgesics within the population studied (Adamczyk et al., 2008, Castro-Sánchez et al., 2012, Kachanathu et al., 2014). Two other of the included studies only specifically mentioned the use of corticosteroid treatment in the last two weeks warranting exclusion. The others mentioned both. Clearly, the use of analgesics within the groups would have an impact on the results, and therefore future studies should consider either excluding those using analgesics or effectively documenting this to ensure levels between experimental and control groups are equal and reduce the chance of this confounder influencing the results.

Other limitations of this study occurred during the search and retrieval of relevant studies. The exclusion of non-English papers is a potential barrier. In particular, three studies had abstracts in English and illustrated papers that possibly could have been pertinent to this paper (Adamczyk et al., 2008, Kim et al., 2002, Park et al., 2010). Another limitation is that this paper solely addresses nonspecific chronic back pain. Several studies were excluded due to the presence of pathology or anatomical abnormalities. One such paper discussed LBP in those with sacroiliac dysfunction (Lee et al., 2014). Although this term has a broad use, this was excluded on the basis that this anatomical or biomechanical anomaly may influence pain and therefore before correction of this pain and disability would have modest improvements. Another study addressed LBP related to menstruation. I opted to exclude this paper due to 2 reasons: Firstly, hormonal changes may have resulted in ligamentous laxity which contributed to the pain (Pollard et al., 2006) and KT's proposed mechanism of action has no influence upon this, secondly the study control group involved applying KT during different stages of menstruation (Bakhtiary et al., 2015) and therefore would not have been relevant for this study.

3.5 Conclusions

3.5.1 Clinical Implications

In conclusion, this review determines that KT does not appear to offer clinical benefits when compared to other treatment modalities. In fact, there is very limited evidence that treatment including KT is less effective than usual care at reducing disability when assessed by the RMDQ. It should be noted, that these results were not replicated when using ODI or the QBDS which included heterogeneous studies without significant findings. Greater homogeneity is needed between future studies, and therefore these results should be

referenced with caution, in particular, the use of analgesics, taping technique and sham therapy applied.

Individually within some of the included papers, although KT did produce a statistically significant decrease in VAS and RMDQ they concluded that this was not deemed clinically worthwhile as an alternative to conventional therapy. It has been suggested that this method also has its own practicalities. Some reports raised the issue as to whether the tape may offer immediate alleviation of pain, which appeared to be supported by the more rapid decline in VAS during initial stages of treatment in the small number of studies which recorded these results. Recently, Kelle et al. (2016) have published a paper, addressing this finding, looking into the effects of KT on acute non-specific LBP, and reported a positive result. KT, therefore, may be used as an aid in early rehabilitation to reduce pain immediately or as an alternative pain management support for athletes when analgesics are a sensitive issue.

3.5.2 Implications for further research in this thesis

Current evidence suggested that applying KT has no overall beneficial effect on LBP management, but it was judged possible that further research was required in this field to ensure no sub-groups were missed and a type two error made as a result – that is, ceasing treatment that does have some benefit if applied in a particular fashion. For example, a greater understanding of KT's mechanism of action is needed. This would allow better formulation of both an adequate placebo and KT therapy. This would, therefore, permit the collection of more accurate results.

Apart from the mechanistic investigation, subgroup exploration also plays a critical role in future decision making. A few subsequently published studies have emphasised the value of further KT research. For example, the work by Kelle et al. (2016) into the effects of KT on acute pain argues that KT may help to reduce drug analgesic use in the acute phase. Correspondingly, Kaplan et al. (2016) indicated that KT might be used to control pregnancy-related LBP effectively. Since there are still some patients that can benefit from receiving KT treatment, it is worth beginning to identify subgroups. For example, one recently published study sub-grouped their LBP patients by severity of the conditions and found patients with severe pain had a more obvious response to KT therapy (Chang et al., 2017). The further study direction should, therefore, start from appraising the actual mechanism of KT alongside with subgroup explorations.

In summary, this review found similar results to published works in that KT has no beneficial effect in LBP care, which contrasts with its popularity. Before discounting it as a therapeutic

adjunct, the focus of the present project needs to be switched from examining the effectiveness of KT to considering its therapeutic mechanisms and responder sub-groups. This was done in order to clarify the mechanisms of KT and explore subgroups of people with LBP who respond to treatment differently. Confidently, switching focus may ultimately help clinicians to decide whether KT should be kept in the toolbox of LBP care or not.

CHAPTER 4 METHODOLOGICAL DEVELOPMENTS

4.1 Overview

The aims of my PhD were focused on KT applications, and particularly mechanisms of effect. Therefore, its influences on soft tissue biomechanics, body segmental kinematics, and muscle activation were included in my observation parameters. Although adequate methodology for these biomechanical parameters has been previously developed, some adjustments and customised design have been undertaken to suit the unique nature of this study. For example, diagnostic ultrasound is a well-developed in-vivo tool for monitoring real-time tissue characteristics, but lacks a robust quantitative method to measure fascia gliding and deformations. Hence, ultrasound-based in-vivo soft tissue observation became a key measurement tool underpinning the subsequent investigations.

The in-vivo ultrasonic assessment methodology was developed in order to explore the effects and mechanisms of KT. The primary purpose of the ultrasonic tool was to investigate dynamic movements and deformation of the connective tissue between skin and muscles in the thoracolumbar area. Apart from ultrasound-based tissue properties investigations, a full body motion capture system (as described in section 4.4.6.2) and a multi-channel electromyography system (as described in section 4.4.5.4) were also used to obtain body segmentation and muscle activity respectively, while participants performed carefully chosen movement tasks. This method will provide an insight how spinal soft tissues respond to KT application during lumbar flexion movements.

4.2 Participants

4.2.1 Ethical procedures

All studies within this PhD project were conducted in accordance with the Declaration of Helsinki (General Assembly of the World Medical Association, 2014). Ethical approval for all observation studies was obtained from the Queen Mary University of London Ethics of Research Committee (QMERC). All participants were provided information sheets with sufficient time to ensure they fully understood research procedures before taking part in the

study. Subjects understood that they could withdraw their participation at any time without providing any reason.

Safety considerations were strongly considered at all stages, with measurement methods chosen as safe non-invasive methods to collect bio-signals, pictures and videos. Participants were not exposed to any harmful radiation during data collection. For example, ultrasound scans consist of low-frequency sound waves, which create images by calculation of reflected wave speeds and timing. Electromyography electrodes receive micro electricity from the human body rather than transmitting electricity to the body and our motion capture system uses infra-red signals. All measurements pose minimal or no potential harm.

It was another consideration that privacy in the data collection areas would be maximised. All images were saved in a locked machine which only the research team has access to. All images were saved and annotated with project and subject codes, which means no personal information was saved or related to images. Subjects were encouraged to bring suitable clothing. Male subjects were suggested to remove sufficient clothing and wear shorts, and female participants were requested to wear sports bra/vest and shorts to enable the ultrasound probe to be applied to the torso with ultrasound coupling gel. In an improbable case of a given participant having a previously unknown skin allergy, allergy tests were carried out prior to data collection. A small piece of KT was then applied to the arm for 20 min before the trial to ensure the subject was not allergic to the tape. No incidences of skin irritation were detected or reported during data collection.

The Investigator explained all procedures to each participant before data collection; participants understood that this study causes no injury. All data collection was performed with the subjects' informed consent. Participant Information Sheet including detail information was given to the participants before. Consent Forms were filled and signed by each participant before the survey.

Each participant was protected from harm or injury with measurements being undertaken in a controlled manner. In some cases, the participant might have increased pain during repeated measurements, and where this occurred the experiment was ceased immediately, and the subject referred to suitable practitioners.

Even though ultrasound is a common diagnostic tool, all participants were aware that they would not receive any form of diagnosis during data collection. However, if any abnormal finding was identified during the ultrasound scanning, subjects could be referred to suitable

health practitioners, and sources for further information about LBP is available in the Participant Information Sheet.

4.2.2 Recruitment, inclusion and exclusion criteria

Participants were approached in several ways. Advertisements, including details of the research project, its purpose and objective, were posted around the university campus (Appendix B). The advert reflected the affiliation with QMUL. This advert was subject to consideration by project supervisor Dr Morrissey prior to use and cleared by the QMERC committee. Participants without a LBP history were recruited in the initial stage for methodology development and asymptomatic observation study. People with LBP were recruited at the later stages to compare with asymptomatic data and potentially for sub-group analysis. The LBP definition was considered across the criteria stated in the existing publications (Added et al., 2013, Castro-Sánchez et al., 2012, Chen et al., 2012, Langevin et al., 2011, Langevin et al., 2009, Paoloni et al., 2011). The detailed inclusion and exclusion criteria for participant recruitment are listed in Table 2. Known specific LBP cases were excluded accordingly. Volunteers in the non-LBP group were defined as people who had no history of LBP during any activities of daily living or work, and other chronic pain that had limited their function. Furthermore, the same exclusion criteria were applied to minimise the possibility of including people without LBP but at high risk of developing LBP.

Table 2. Comparison of Inclusion and exclusion criteria for subject recruitment.

Author / year	Objective	Inclusion	Exclusion
Present project	Objective: Fascia movement fascia deformation Muscle activation Kinematic change pain reduction Subjects: LBP / non-LBP Groups: All subjects performed tasks in tow conditions (KT taping / No Taping)	**LBP** - currently presenting with *simple LBP of severity greater than 5/10 VAS intermittently during the day (*Simple LBP is located entirely between the levels of the bottom rib and the back of the knee, and has no definitive cause) - LBP episode duration longer than 5 days with at least one month relatively pain-free (no >2/10 VAS) before this episode - **multiple episodes** over a 12-month period acceptable but not essential **No-LBP** - The absence of current LBP. - No history of LBP lasting greater than 48 hours in any episode - no other history of chronic musculoskeletal or fascial pain	**Had diagnosed:** - spinal pathology, - major trauma, - systemic disease, - cancer - osteoporosis - inflammatory disease - neurological deficit **Specific exclusion criteria** - pregnancy - previous back surgery - waiting for surgery - corticosteroid medication - corticosteroid injection on the back - nerve root symptoms - any red flags - paresthesia - bladder or bowel dysfunction - bilateral leg pain - history of spinal trauma; **Known skin sensitivity to tape, dermatitis or a pre-existing skin lesion over the taping area.**
CASTRO-SÁNCHEZ et al. 2012	Objective: Pain/disability reduction Subjects: LBP Groups: Fascia taping Placebo Taping	**LBP** - At least 3 months - Score of 4+ on R-M LBP Disability Questionnaire - Not achieve flexion-relaxation in lumbar muscles	- Radiculopathy - Lumbar stenosis - Fibromyalgia - Spondylolisthesis - Previous Spinal surgery, Kinesio tape therapy, corticosteroid treatment in past two weeks. - Central or peripheral nervous system disease
PAOLONI et al. 2011	Objective: Pain/disability reduction EMG F-R Subjects: LBP Groups: KT + exercise, KT, exercise	**LBP** - Lasting > 12 weeks - Fail to achieve FR in lumbar muscles	- Radiculopathy - Lumbar stenosis - Spondylolisthesis - Previous spinal surgery, corticosteroid treatment in past two weeks. - Central or peripheral nervous system disease

Table 2. Comparison of Inclusion and exclusion criteria for subject recruitment (continued)

Author / year	Objective	Inclusion	Exclusion
ADDE et al. 2013	Objective: Pain reduction Subjects: LBP Groups: Fascia taping Placebo Taping	**Chronic non-specific LBP** - More than three months and seeking treatment.	- Have any contraindications to physical exercise - Serious spinal pathologies (fractures, tumours, and inflammatory pathologies such as ankylosing spondylitis); - Nerve root compromise (disc herniation and spondylolisthesis with neurological compromise, spinal stenosis, and others); - Contraindications to the use of KT (allergy or intolerance), - Serious cardiorespiratory diseases or pregnancy.
LANGEVIN et al. 2009 **LANGEVIN et al. 2011**	Objective: Fascia thickness/shear strain Subjects: LBP, non-LBP Groups: LBP, non-LBP	**Recurrent / Chronic LBP** - LBP present on less than half the days in a 12-month period, occurring in multiple episodes over a year. - Back pain present on at least half the days in a 12-month period in a single episode **No-LBP** - the absence of a history of LBP or any activities of daily living or work and a current numerical current pain index of less than 0.5 (on a 10-point VAS) other chronic pain that had limited	**Both groups** - Back or low extremity injury or surgery; - major structural spinal deformity: scoliosis, kyphosis, stenosis, ankylosing spondylitis or rheumatoid arthritis; spinal fracture, tumour or infection - nerve root compression; neurological or major psychiatric disorder; - bleeding disorders; - corticosteroid medication or corticosteroid injection at an L2-3 level of the back; - pregnancy; - acute systemic infection
Chen et al. 2012	Objective: Pain reduction Subjects: LBP Groups: Fascia taping Placebo Taping	**Non-specific LBP** - Back pain localized between the lowest rib and gluteal creases with or without leg(s) pain and with no definitive cause. - Duration of an episode more than 6 weeks or recurrent LBP defined as an episode of LBP longer than 24 hours with at least one-month pain-free before and after the episode and multiple episodes over the year.	- Had diagnosed spinal pathology, major trauma, systemic disease, cancer, osteoporosis, inflammatory disease or neurological deficit. Specific exclusion criteria included pregnancy, previous back surgery or waiting for surgery, or active or pending legal proceedings due to their LBP. - Had skin sensitivity to tape, dermatitis or a pre-existing skin lesion over the taping area.

4.2.3 Sample size and power

4.2.3.1 Estimating sample size

Although an innovative analysis method was used in this project, meaning measurement values including means and standard deviations would likely be different from other studies, calculations based on existing published data were performed to estimate required sample size. A desired level of $\alpha \leq 0.05$ and 80% power (1-β) were set for prospective sample size calculation. A measurement study by Yoshida and Kahanov (2007) showed a significant mean ROM difference of 17.8 cm after taping (Taping: 81.5, non-taping: 63.7, t (29) = 2.51). Although no standard deviation was reported in this study, the effect size can still be estimated from actual T value and degree of freedom. This showed a required sample size of 17 to demonstrate such difference in the same group repeated measured design. Another pain measurement study by Chen et al. (2012) showed a mean difference in pain intensity between groups of 17.3mm (Taping: 35.5 ± 22.9, Control: 18.2 ± 23.9) on the VAS. This showed a sample size of 24 in each group was required in order to ensure 80% power level in the between-group comparison. According to statistical setup and previous studies, an estimated target of 17 participants was set for each sub-project. Actual power calculations were performed alongside the actual statistics to estimate statistical power.

4.3 Experimental design and movement tasks

4.3.1 Study design

This PhD thesis contains four sub-projects, namely methods developments, two observational studies and a laboratory-based control study. An innovative ultrasound based tissue measurement method was initially developed for the primary aim of this study. Along with two other available biomechanical measurement methods, two other studies have been conducted to answer the research questions.

Two observational studies were conducted to discover if KT can affect dynamics and properties of subcutaneous tissues. Both sub-projects were cross-sessional observation studies. The first observed the immediate effect and mechanisms of KT in asymptomatic participants (Chapter 5.1). Tissue movements, muscle activations and joint kinematics were observed before and after participants received single strip para-spinal taping with Kinesio-tape (as described in section 4.4.1.3.2). The second observational study was carried out through collaboration with the Faculty of Sports Sciences, University of Nantes. Shear-wave elastography, which is also a newly developed ultrasound-based measuring method, was used to observe the difference in tissue stiffness before and after taping (Chapter 5.2).

Following these observational works, an asymptomatic human observational study was performed to confirm if people with LBP have a similar soft-tissue response to those pain-free participants (Chapter 6). The ideal setting for these sub-projects would be a prospective study or a large trial with mechanistic exploration, but a snapshot cross-sectional design was chosen because it was feasible within the short period available and to optimise recruitment.

4.3.2 Test manoeuvre

A simple lumbar flexion-extension experimental movement task was chosen, during which lumbar tissue dynamics and deformations could be assessed. The task is to bend forward from 0° to approximately 90° of lumbar flexion lumbar flexion. Participants were initially standing in a neutral position, and then they were advised to bend forward to touch their toes or as close as was possible without bending the knees (Figure 8)

Speed control of the movement task allowed the investigator to have better control of the US probe and prevent variable speed confounding results, which stabilises the data collection procedure as well as normalises the length of each data period. However, it was recognised that movement under strict speed-control is different from real life movement and difficult to ensure. The experimental task was designed with consideration of some pros and cons of controlling the movement speed (detailed comparisons are listed in Table 3).

To minimise the influence caused by speed control, a metronome set at 90 beats per minutes was used to provide a time guide to normalise movements as much as possible. Participants were advised to start their movement in the first beat and finish their forward bending in the fourth beat and return to a natural position at the same speed – to start in the 5^{th} beat and end in the 8^{th}. Participants were allowed to have several practices to get familiar with this experimental movement before data collection in order to perform the action smoothly and avoid unnatural action or pauses while the ultrasound recording was taking place. The speed and range of motion might be slightly different between subjects; however kinematic data were recorded synchronously using a motion capture system for later normalisations. Relative movement and trunk angle registration were used in analytical comparisons between different conditions.

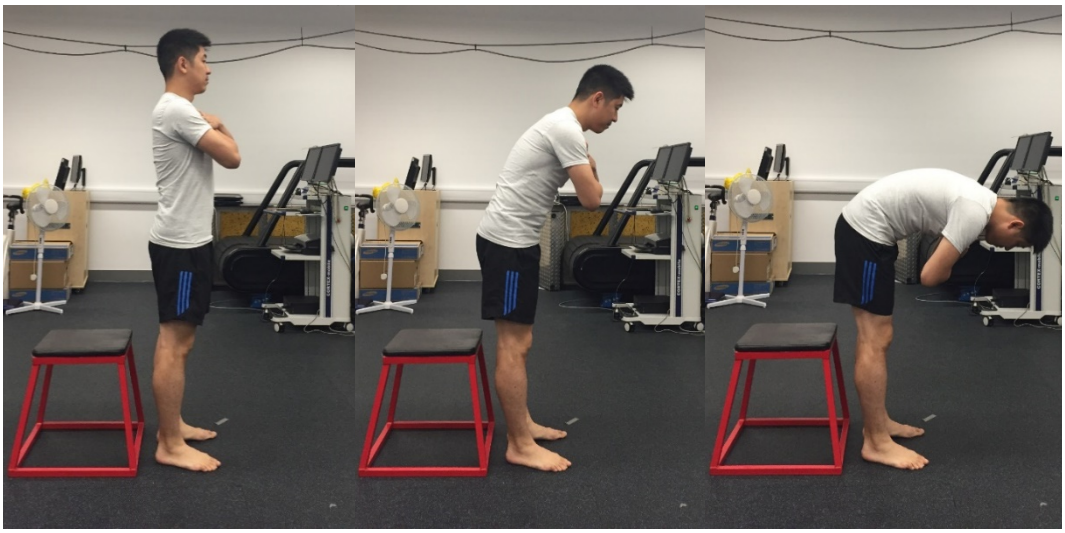


Figure 8. Demonstration of the experimental lumbar flexion-extension movement task
Left: initial neutral posture; right: end of flexion posture

Table 3. Comparison of advantages and disadvantages of controlling the movement speed.

	Control the movement speed	**Not to control movement speed**
Advantages	• Allow collecting stable and similar movement data across all subjects • Easy to control the US probe in isokinetic movement	• Allow the subject to perform this experiment in a natural way.
Disadvantages	• Subjects need more time to learn the required speed • Not natural movement, isokinetic movement rare in real life • May distort the reality of low back movement for individuals • Not every subject can perform lower trunk motion smoothly when given an externally determined tempo to follow	• May allow subject to move faster to achieve better range of motion. • Difficult to normalise different speeds of movement across subjects, and the speed may change biomechanics

4.3.3 Taping Procedure

Several application techniques are currently used in treating patients with LBP. To minimise the effect of individual therapists, in this study taping was applied using I-shape strips taped over one erector spinae muscle, parallel to the spinous process of the lumbar vertebrae (Figure 11). Before taping, participants' skin was checked to make sure that there was no pre-existing skin lesion over the taping area. KT was applied to a single side of the muscle, a computerised random number being used to decide which side to tape. Tapes were applied

with 10% of tension (paper-off tension[1]) from the top of the first sacrum up to the bottom edge of the T12 vertebrae (treatment area). Two anchors with 0% tension were then applied above and below the treatment area. To control taping tension, the length of the taping area was measured before taping, and the tape was cut accordingly. As recommended by the KT application guidelines (Kase et al., 2003), while applying taping the patients were asked to fully flex their lumbar spine to their natural end to stretch the erector spinae muscle and overlying skin. Consequently, the tape created convolutions when the subject stood in neutral. In order to perform ultrasound scanning, a 5 x 1 cm window beside the L2 and L3 vertebrae was cut from the tape strips (Figure 11).

4.4 Data collection and processing

4.4.1 Ultrasound measurements

4.4.1.1 Rationale of using ultrasound

A diagnosis ultrasound was used in this PhD project. Ultrasound is an ideal tool to investigate the objectives of this project because it offers a non-invasive real-time in-vivo assessment which has minimal influence on movements. Because the machine used in this project was made for diagnosis purposes, it is proved to have a reliable validity in the assessment of a variety of human tissues. For example, a systematic review reported adequate levels of reliability and precision for the quantification of abdominal and lumbar trunk muscle thickness or cross-sectional area with ultrasound imaging, Intra-image measurements demonstrated good intra-rater (ICC > 0.93) and inter-rater reliability (ICC > 0.91) and Inter-image measurements demonstrated good inter-rater reliability (ICC > 0.90) among six included high-quality studies (Hebert et al., 2009). Ultrasound is, therefore, a good tool to be used in learning and researching purposes. Particularly in this project, it was used to observe tissue characteristics and properties of soft tissues in the thoracolumbar area during movements. As a non-invasive imaging technique, it allowed me to minimise the influence of body movements during image capturing on the soft tissue of the thoracolumbar lumbar. Even though current diagnosis purposed ultrasound machines were not specifically designed to investigate tissue properties and dynamics, such as gliding movements, deformations and percutaneous translations, its potential for innovative applications should not be ignored.

[1] The tape is expended to 104 - 105% of its original length when manufactured. As the tape can be expended to 140% of its original length, current KT guidelines usually consider this tension as 10% or paper-off tension.

The other important reason to use ultrasound imaging as a key assessment in the present project was simple availability. A number of ultrasound-based studies had been done in the Human Performance Lab before I joined the team (Divani et al., 2010, Emerson et al., 2010, Malliaras et al., 2013). A device and the required technical help was therefore readily available. Although the machine was not the most modern ultrasound model, and had a few limitations in the context of my project objectives, for example, I cannot access the radio frequency (RF) signal data and the probe width is short, so my processing method had to be developed based on exported image files, which have been converted and processed by the built-in algorithm of the manufacturer. These built-in imaging process usually contains smoothing function in order to improve image quality for clinical pathological structural diagnosis, however, this reduced my flexibility of choosing different smoothing and filtering method, which may potentially be more suitable for my analysis purposes. Taking on this challenge was a key part of my PhD journey, with developmental works on image processing to obtain suitable data for the purposes of the project a key enabler.

4.4.1.2 Alternative tools

Apart from B-mode ultrasound, a few other tools were also considered in the present project, such as Sono-elastography which access tissue elasticity through b-mode ultrasound; dual plane fluoroscopy which uses two orthogonally arranged devices to create 3-d images, or Magnetic resonance imaging which is a common diagnosis tool used for providing cross sessional two dimensional images in three planes. Aside from availability and cost, the most important factor is to consider was whether the features of each tool matched the aim and objective of this project. For example, most of the current in-vivo medical imaging techniques require the subject to adopt one particular posture, and therefore would not be able to extract dynamic information of soft tissues which is important in the discussion of the mechanisms of KT. One of the standard instructions of KT therapy is to encourage patient to move with KT application so the skin and subcutaneous tissue can receive stimulation continuously form the tape. Therefore, the ability of exacting parameters during movement is an important concern in this PhD project.

Ultrasound elastography is an alternative measurement which can assess tissue elasticity through b-mode ultrasound signals. This provides information on tissue deformability (Shiina et al., 2002). The elasticity of soft tissue can be affected by disorders such as tendinopathy, neuromuscular disease or during wound healing (Klauser et al., 2014), ageing and after training. For example, a study demonstrated that Achilles tendon with tendinopathy is softer compared with normal tendons (De Zordo et al., 2009). This technique is sensitive and

accurate when compared with clinical findings (De Zordo et al., 2009). Elastography also has the potential to quantify muscle force, Killian et al. (2011) reporting that elastography has a higher accurate estimation of individual muscle force (R^2 = 0.98) comparing with surface electromyography (R^2 = 0.95). It is, therefore, a potential tool to provide the first-line detection of soft tissue biomechanical changes in tendon, ligament or muscles. However, there is still some limitation and drawbacks requiring consideration. For example, sono-elastography requires a modest distance (usually 3 mm) between probe transducer surface and the target tissues (Klauser et al., 2010). Thus, assessing skin and superficial fascia, which is important in the present project, can be a challenge. After checking the quality of shear wave data, I decided to exclude the skin stiffness measurement in Chapter 5.2.

The other concern that elastography has a limitation on a lower sampling rate. For example, this technique measures the tissue elasticity by assessing the propagation velocity of shear-wave generated by an additional sound wave alongside the B-mode ultrasound wave during the imaging process; or by assessing the shear deformation propagating generated by an external directional force (Parker et al., 1998). Therefore, the sampling rate of this kind of measurements relies on either the interval of each additional pulse and the length of shear wave or the frequency of external compression. The ultrasound machine (V6.0; Supersonic Imagine, Aix-en-Provence, France) used in a side project of this PhD for instance, can only do one elastography measurement per second due to the pulse generation rate. It is therefore not suitable to measure tissue properties during quick movements. Therefore, the experiment in Chapter 5-2 had to be adopted due to this limitation.

4.4.1.3 Ultrasound acquisition

4.4.1.3.1 Introduce to the machine and settings

An ultrasound machine (Voluson i, GE Healthcare; WI, USA) with a linear array transducer (GE 12L-RS, GE Healthcare; WI, USA) was used to collect b-mode cine data. This transducer was designed for small parts, vascular, paediatrics and orthopaedics clinical usages. The centre image frequency is 7.5 megahertz. In all data collection, the transducer probe was set to orthopaedics mode with an image retrieve depth of 5 centimetres. The receiver frequency range was 15.50 to 4.00 (MHz), and acoustic power was fixed to the maximum with a gain of 5 decibels (GE Healthcare, 2007). All other settings are shown in Figure 9. The video recording frame rate was limited to 35 frames per second, which may be too low for assessing fast movements, such as jumping or landing, however, the designated movement task in the present project was a speed-guided slow movement which participants were asked to reach

their total lumbar flexion range in 2 seconds and back to neutral position in the same speed. A frame rate at 35 Hz was considered suitable to collect key information for analysis.

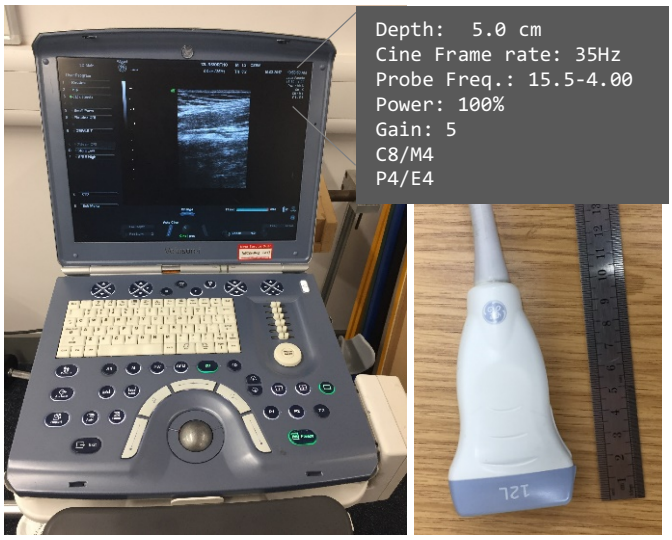


Figure 9. Ultrasound machine settings and probe transducer
Left: an example of ultrasound machine with the image.
Right: ultrasound probe transducer

4.4.1.3.2 Acquisition Procedure

A simple lumbar flexion-extension experimental movement task was chosen to assess the tissue dynamics and deformations during lumbar movements (Figure 8). Many tissues in the thoracolumbar area are involved in lumbar flexion movements. As shown in Figure 10, apart from erector spinae muscles and multifidus muscles, a fascial junction of various muscles, such as latissimus dorsi, serratus posterior inferior and oblique abdominal muscles, are connected in the thoracolumbar area. Tissues in this area have a larger size than the ultrasound transducer, and KT is usually applied to affect these tissues. The taping effect, therefore, may appear in all areas where KT was applied. I had to choose a small window to observe due to probe size. The location of the transducer was adapted from a previous study which suggested a point of 2-centimetre lateral to the middle of the level 2 and 3 of lumbar spinous processes, because the fascia planes are optimally parallel to the skin at this level of the lumbar area (Langevin et al., 2011, Langevin et al., 2009) therefore providing better accuracy when image processing.

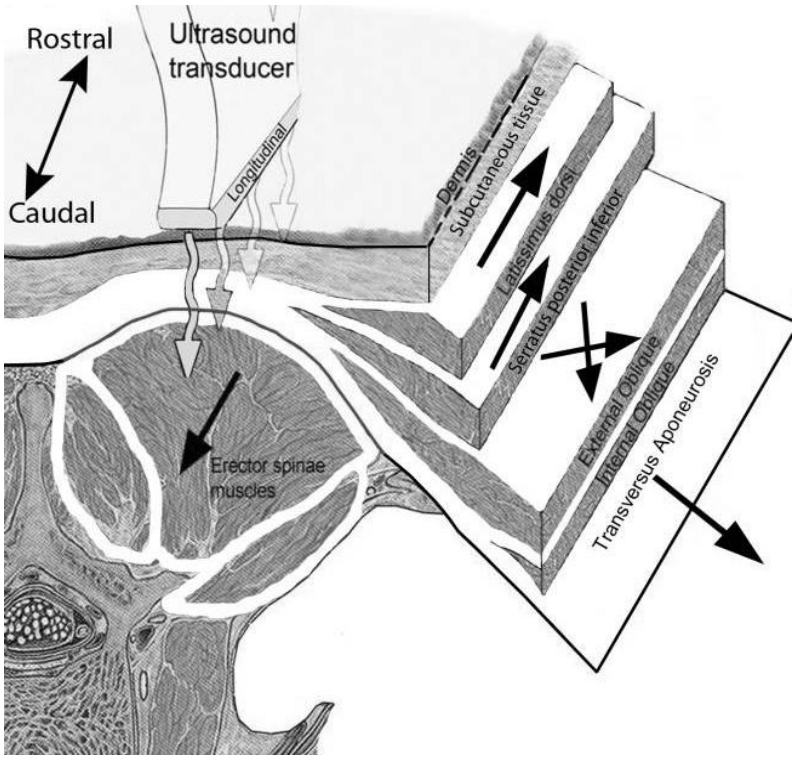


Figure 10. Cross-sessional anatomy of thoracolumbar area (Langevin et al., 2011)

The alteration of probe placement in the present project was to use a point 3cm lateral from the spinous processes instead of 2cm in order to allow more space for KT (Figure 11). By this alteration, more space overlying the thoracolumbar fascia can be reserved for EMG electrodes and Kinesio tapes in order to maximise the quality of signals and taping stimulations. However, the transverse vertebral processes may be excluded from the images due to this alteration, which is, therefore, a disadvantage. The transverse processes can be a useful visual landmark to make sure the scan remains in the same plane at all times. A few remedial measures were taken to minimise the negative effects. For example, ultrasound-guided palpation located the second and third lumbar vertebrae. Skin marks were made during the palpations, and the probe transducer can then be placed in the same position at all times. When performing trunk flexion, the caudal end of the transducer was stabilised on the subject's skin, and the skin allowed to slide at the rostral end to enable measuring skin movements. This procedure minimised overall sliding of the probe. Apart from this, a transducer probe frame (as described in section 4.4.1.5.2) was designed to avoid swinging in the coronal plane which helped to maintain ultrasound beam orientation.

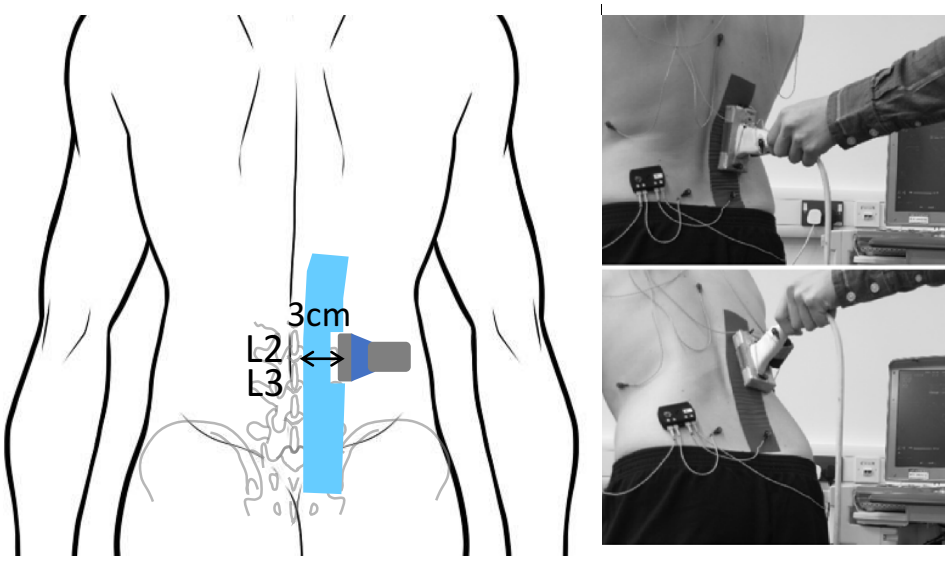


Figure 11. Position of ultrasound probe transducer and Kinesio-taping

4.4.1.4 Training in ultrasound use

Since ultrasound imaging took an important part of the present PhD project, and I am not trained as a radiologist to use ultrasound as a diagnostic tool, a number of formal and informal training events were undertaken before and during this study to ensure the reliability and quality of ultrasound data included in my project. The informal training includes lab equipment training and daily scanning practices through meat, phantom and the human body; the formal training was taking a level 7 medical imaging module (WHR7033) in the Department of Sports and Exercise Medicine.

4.4.1.4.1 Informal training - Scan through a cut of meat to line the object and images

Although the machine reliability and validity had been proven before it launched to the market, a few reliability and validity tests were done prior to the actual data collection procedure to ensure research quality in my hands. Apart from checking reliability and validity, this was also an informal training which is an important part of the present project. In the first stage, a cut of meat with spinal joints was used to learn ultrasound beam control and target identification (Figure 12). Extended-view mode was particularly useful in verifying the image when comparing the pictures of the object and the ultrasonic images (Figure 13.A and B). After familiarising with machine operation, pins were implanted into pork skin with intervals of one centimetre for further image capture and measurement training.

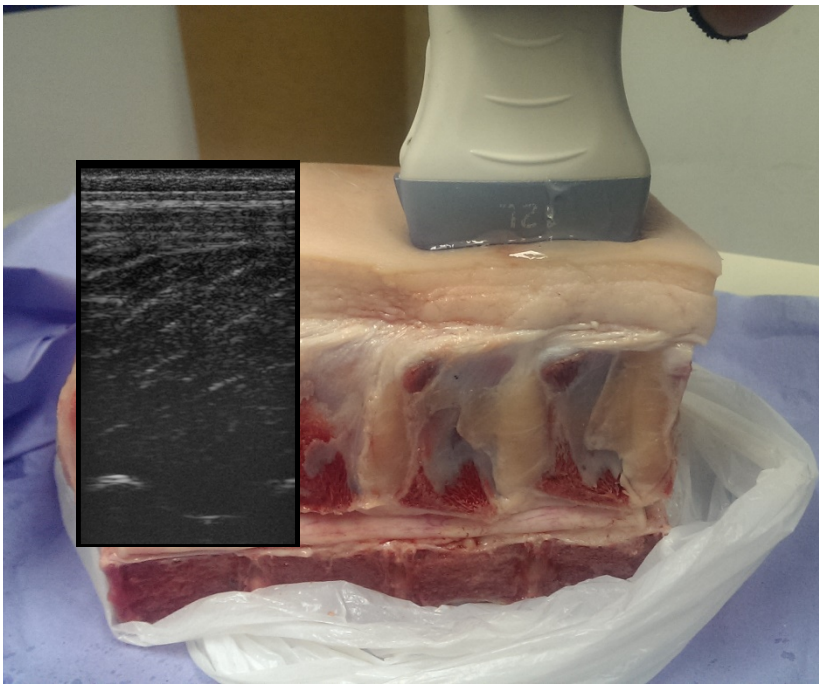


Figure 12. Ultrasound scanning learning and verifying image from a cut of the porcine spine.

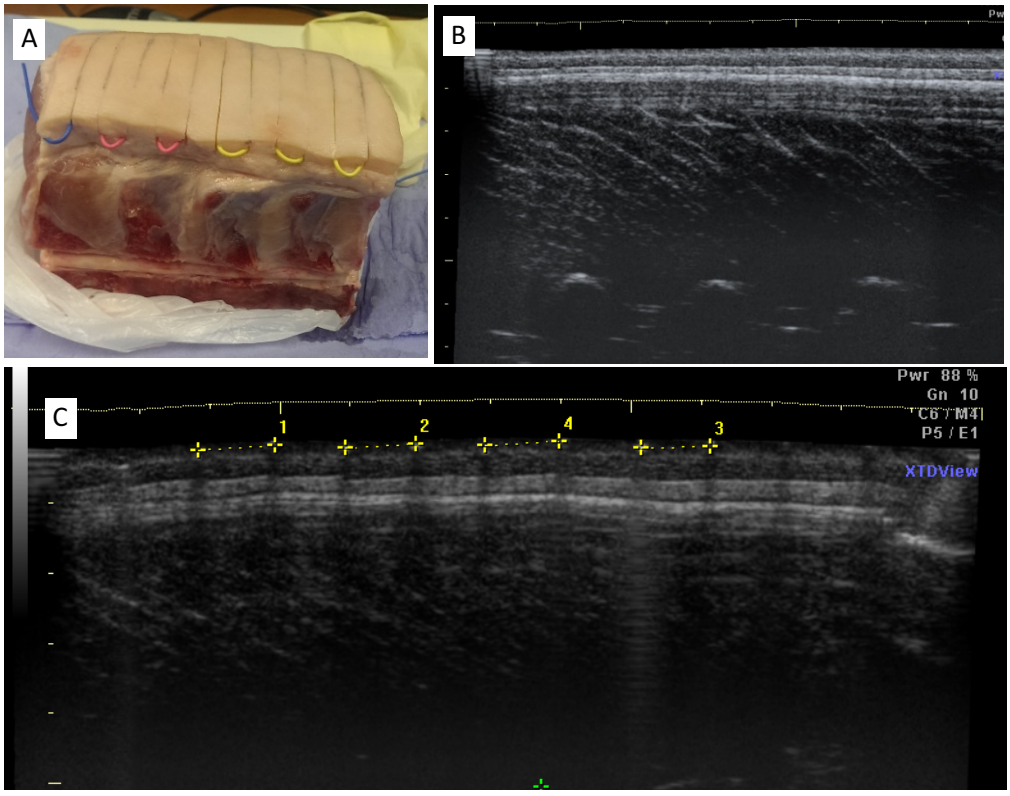


Figure 13. Ultrasound scanning learning and verifying measurements from a cut of porcine spine

A: A cut of pork spine with pins inserted for visualisation

B: Extended-view ultrasound image captured from the pork without pin markers

C: Extended-view ultrasound image captured from the pork with pins on the skin

4.4.1.4.2 Imaging module

Sports and Exercise Medicine provided a level 7 module - WHR7033 - Imaging in Sports and Exercise Medicine every year as it is now becoming an essential skill for Health Care Professionals who work in sports to understand the theory and practical application of the range of diagnostic modalities available. It was, therefore, an excellent opportunity for me to take this module as preparation for the present project.

The aim of this module was to provide an understanding of the physiological and technical basis of imaging modalities in Sports Medicine, and an in-depth knowledge and understanding of the selection of appropriate imaging techniques based on clinical situations. Therefore, this module provided a comprehensive review of the most widely-used methods of medical imaging in most common conditions and an introduction to the parameters that define image quality, modalities. Its curriculum includes:

- basic principles of medical imaging
- associated instrumentation
- method of image extraction in clinical settings
- Practical application in sports injuries.

The most important and relevant development for my PhD study was practical skills in ultrasound scanning and knowledge of the image interpretation. This part was originally designed for health care professions working in sports medicine in line with recommendations from professional bodies. The module included several intensive ultrasound training covering all parts of human body. Apart from image diagnosis, the lecture also deconstructed the skills to a detailed level. For example, from basic knowledge of applied physics and principles of application through to image capture and management; from normal anatomy to pathological images.

The most important consequence of taking this module is that it increased my confidence in capturing ultrasound images, and the instruction from a world-leading musculoskeletal radiologist enabled me to better manage the experiment quality.

4.4.1.5 Innovations: analysis during movement

Although research interests related to LBP have focused on the biomechanical characters of the thoracolumbar fascia, and some ultrasonography based analyses have been used (Bishop et al., 2016, Langevin et al., 2009, Luomala et al., 2014, Mohseni-Bandpei et al., 2014), no standard methodology to quantify movement and biomechanical properties of the fascia in

vivo has been developed yet. Therefore, the primary aim was to develop a reliable in vivo measurement technique to enable exploration of taping mechanisms.

4.4.1.5.1 Analysis pack

Instead of using pre-programmed assessment tools provided by the ultrasound machine, MATLAB (R2013a, R2014b, and R2015a, Mathwork; MA, USA) based algorithms were developed to process ultrasound data in order to observe tissue movements, deformations or any other potential tissue properties. This was the most important part of the methodological development. It is important to note that all the algorithms and programmes mentioned in the section were developed by the candidate with guidance and essential helps form Prof Roger Woledge. A flowchart has been provided to demonstrate the overall ultrasound data processing before variable extraction (Figure 14).

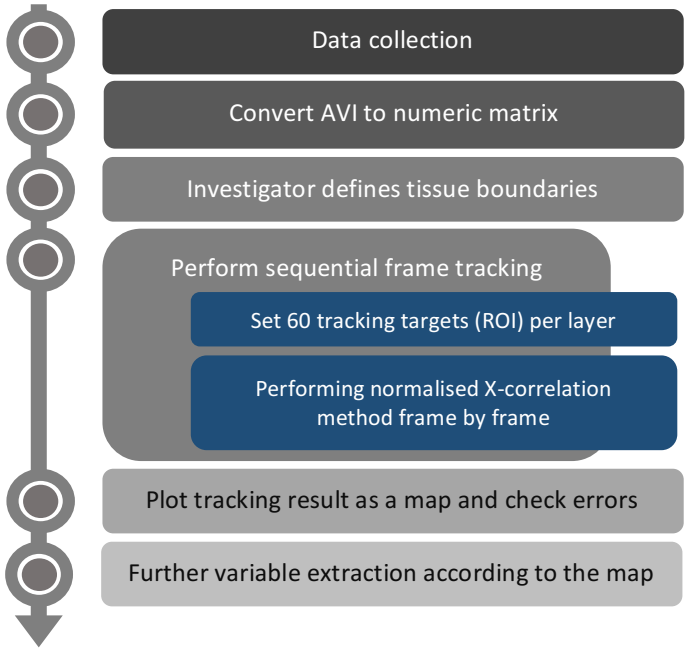


Figure 14. Flowchart of cine ultrasound image processing

Before performing the actual tracking and measurement process, all B-mode ultrasound videos were converted into an echogenicity matrix frame-by-frame. Although analysis through raw radio frequency responses is a more profound way to investigate tissue movements and properties, the provided ultrasound machine (Voluson i, GE Healthcare; WI, USA) did not allow users to access raw signals. Therefore, videos had to be converted from DICOM image formats to a quantitative matrix containing the brightness level of each pixel in the ultrasound image, this representing the level of echo density of the ultrasound signal

in a particular depth and position (Figure 15). After numeric conversion, the investigator recognised and defined layer boundaries for each tissue zone following the codes described in section 4.4.1.5.1.3, and then the programme automatically continues the tracking process. 60 regions of interest (tracking targets) were equally spread in each layer, and the sequential frame tracking (section 4.4.1.5.1.2) were repeatedly performed until all targets were fully tracked. The result was then plotted as a map to enable visual error checks before further variable extraction. Detailed algorithms for each step are described in the following sub-sections.

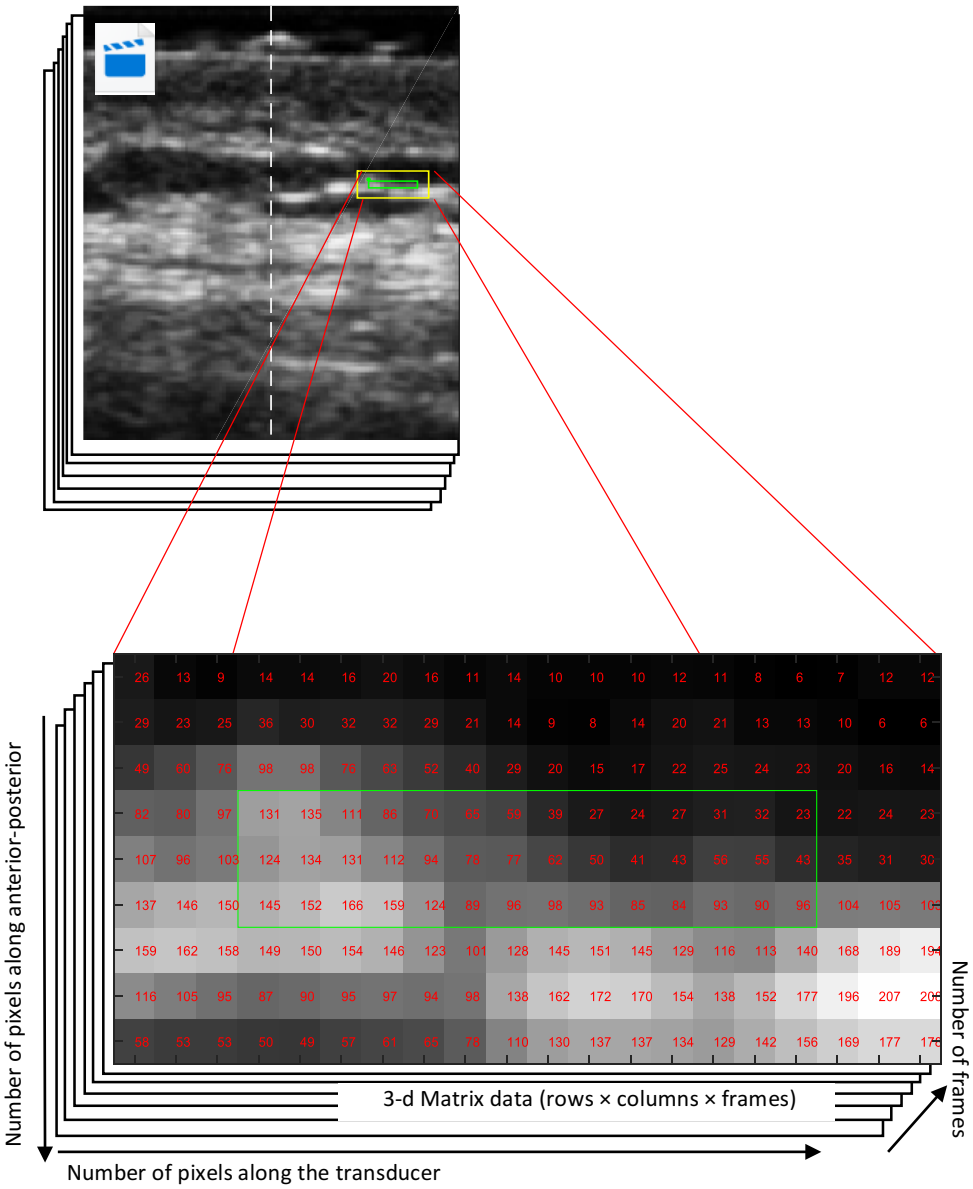


Figure 15. An example of a video-to-matrix conversion.

A video (Scan001.avi) has been loaded into MATLAB and converted to matrix format. Only data within the yellow square has been displayed for demonstration purposes; the same procedure has been performed through the entire image. The brightness scale provides information of echogenicity. The cells of converted greyscale matrix contain values ranges from 0 to 255. zero represents blackest (lowest level of echogenicity), and 255 represents brightest (highest level of echogenicity).

4.4.1.5.1.1 General 2-d cross-correlation application

The purpose of algorithm development was to quantify tissue movements or detect tissue deformations during designated experimental movement manoeuvres via 3D ultrasonic images. A two-dimensional cross-correlation was selected as a core function of the programme. Cross-correlation is a mathematical method that provides information to find the regions in which two signals (images) most resemble each other (Murayama et al., 2000). This method is particularly useful in feature recognition and tracking. It has therefore been used in tracking nerves or tumours in the image-based analysis (Dilley et al., 2001). Figure 16 is an example of identifying a target feature by using cross-correlation matrix. The task was to identify a targeted feature template (Figure 16A) within a bigger image (Figure 16B). The location recognition can be achieved by performing normalised 2-D cross-correlation comparisons which return a matrix (Figure 16C) containing correlation coefficient values. These values range in value from -1.0 to 1.0. The value of 1.0 means the feature template perfectly matched the image. The target could then be located by searching the region within which the highest correlation coefficient value was obtained, (Figure 16D).

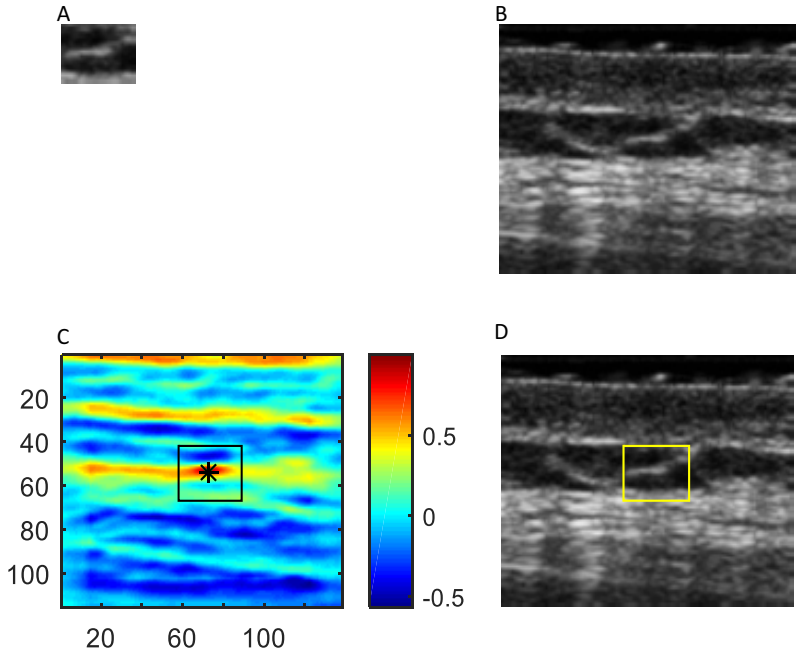


Figure 16. The concept of 2D cross-correlation.

A: Feature template which needs to be located within the large ultrasound image.
B: Ultrasound image of skin, superficial and deeper fascia.
*C: Colour scaled correlation coefficient matrix which represents the similarity likelihood between template A and sub-regions within template B. * marked the peak correlation coefficient values, and the black square indicated the position where is most likely to be identical with the template A.*
D: Demonstration of the result. The yellow square highlighted a sub-region of image B which is the most similar to image A.

4.4.1.5.1.2 Sequential frame tracking

The aim of designing an automatic video tracking algorithm was to accurately quantify subcutaneous tissue deformation, translation and gliding. This can be achieved by observing difference between two continuous frames and repeat the same process through the whole video clip. The core concept of cine ultrasound tracking is to extract a small template form one frame of the image and locate an area which contains the most similar features in the next frame. For example, Figure 17A is a frame of the cine ultrasound clip, and a flat box marked an area of interest which has been selected as a target template from this frame (green box in Figure 17A), and a brightness matrix was extracted from this box. A larger flat box outside the template box, which was an estimated range of movements between two frames, was set as a tracking field (yellow box in Figure 17A), and a matrix was then extracted from the same location in the next frame (Figure 17C). An area in the searching field which contains the most similar feature (Figure 17C green box) to the template can be located by performing cross-correlation searching which returned a colour scaled correlation coefficient matrix. A peak value was found in the centre of the tracking field, which showed no movement between these two frames. Figure 18 gave an example result of movement when a movement was detected. The ‘o’ mark is the centre of tracking field, and ‘*’ mark located the centre of an area which best matched the template. The difference between the two locations demonstrated the amount and direction of the movement.

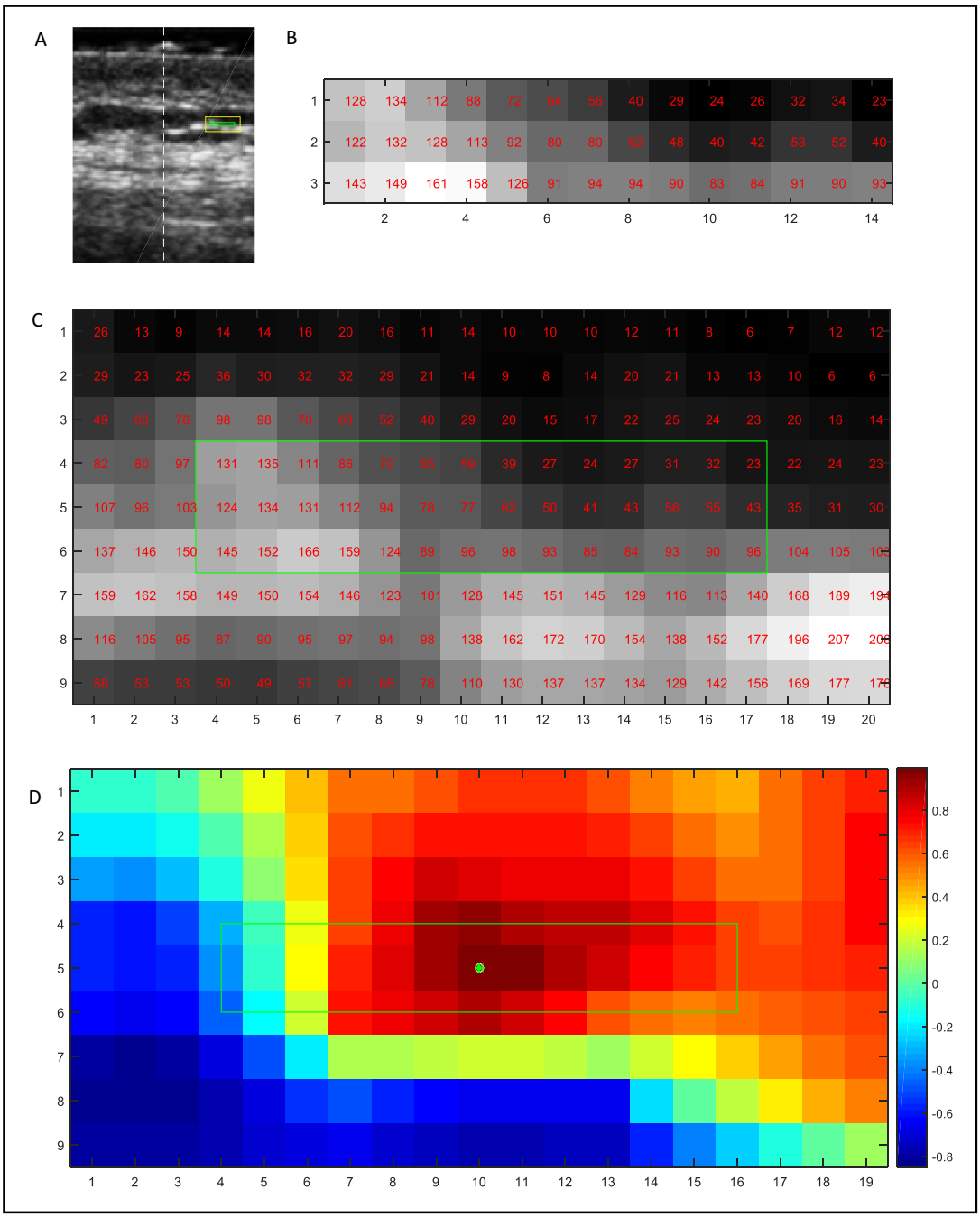


Figure 17. The concept of feature extraction for cross-correlation.

A: a frame of the cine ultrasound clip. Green box marked a target of interest. The yellow box demonstrated the location of tracking field.

B: Brightness matrix extracted from the target template. Numbers represent brightness level of each pixel in a scale of 256, ranging from 0 the darkest to 255 the brightest.

C: Brightness matrix extracted from the next frame in the tracking field. The green box highlighted an area where best matched the template.

D: Colour scaled correlation coefficient matrix returned from the searching template (B) within tracking field (C). The result showed no movement (centre of two images appeared in the same location).

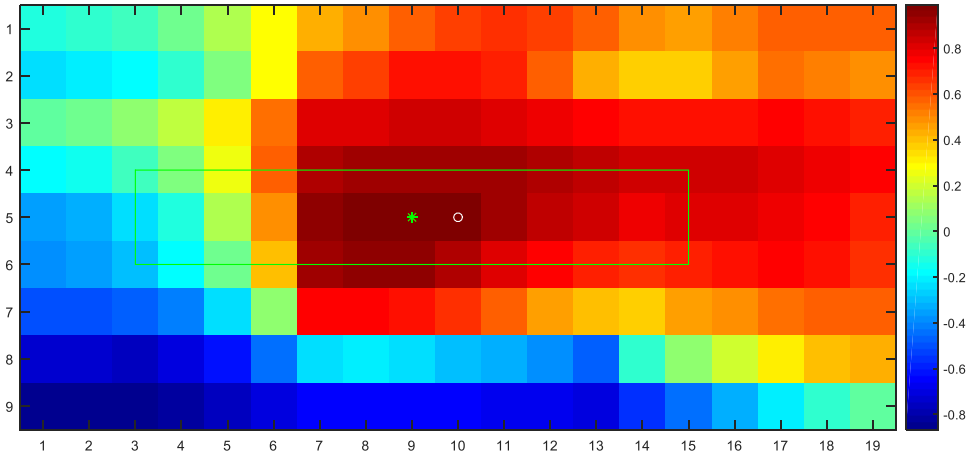


Figure 18. An example of colour scaled correlation coefficient matrix which demonstrates an ROI image movement.

** Centre of the template location*

° Centre of the tracking field.

4.4.1.5.1.3 Video clip movement tracking

Tissue movement during the experimental task can be sufficiently detected by applying and repeating this sequential frame tracking algorithm through the entire videotape. For example, image features within selected ROI in the first frame were used as a template to search for an area, which contains the most similar features, in the second frame. If movement were detected, the features within the new position in frame number two would be updated as a new template to perform a new search in frame number three. The same procedure was performed until all frames within the video clip were searched. Two-dimensional inter-frame movements were recorded for further analysis. Figure 19 is an example result of one single ROI tracking through the whole video clip taken from a participant when performing a full loop of designated experimental movement task. 'O' indicated the initial position of this image feature, and 'X' indicated the final position of this feature. Blue path in Figure 19A indicated the movement route.

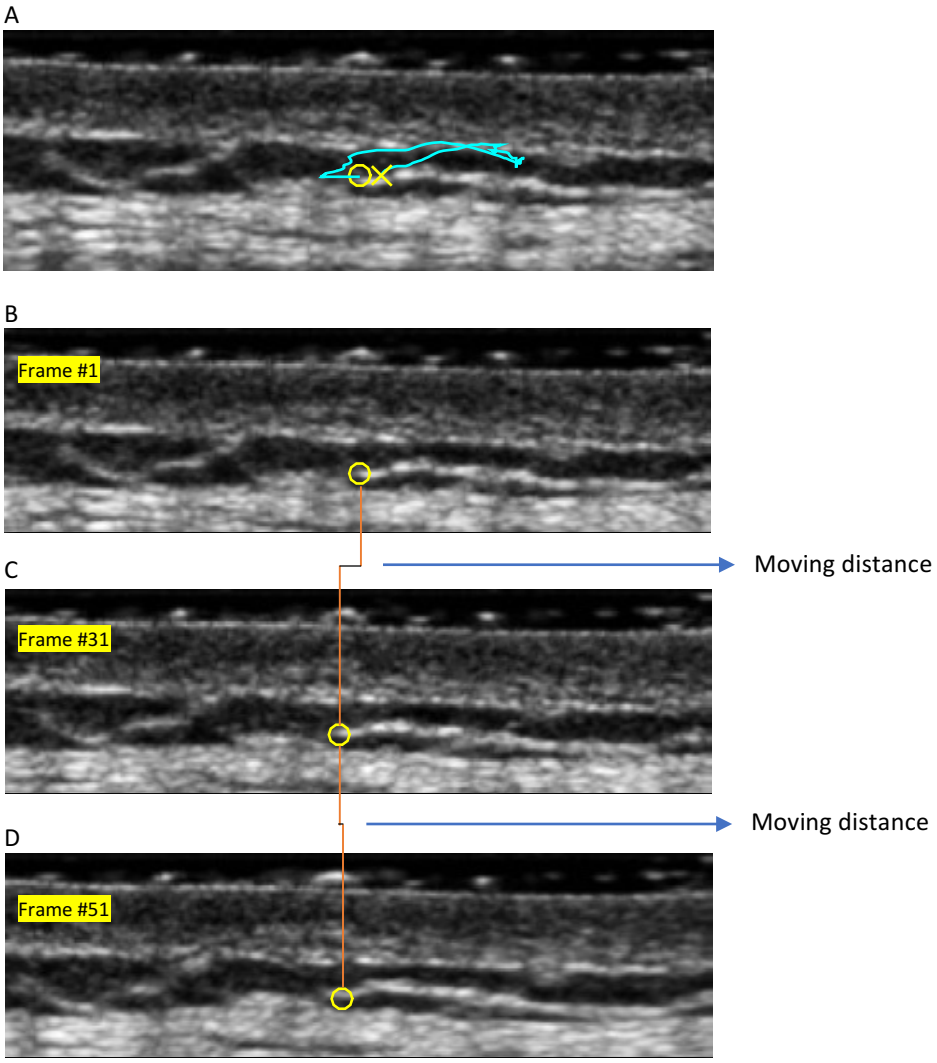


Figure 19. Example of tracking a single feature.

A: O: *original target position;* ***X:*** *target position in the last frame of the video;* ***Blue route:*** *moving path of single ROI*

B, C and D: *Demonstration of initial movement tracking (from frame number 1 through frame number 51), target moved to left initially. The same movement path can be seen in A.*

All collected cine ultrasound images were firstly checked by the primary investigator to visually identify boundaries between skin, superficial fascia (subcutaneous zone), deeper fascia and muscles according to junctions of echogenicity level change before the movements of tissue were tracked by the algorithm. The intra-investigator reliability of this boundary identification was high (ICC = 0.98). The centre area of each layer was defined as an area of interest, and sixty targets were distributed evenly in the contiguous area as shown in Figure 20A. The colour in the figure was simply set to distinguish contiguous targets visually. The programme automatically searched the contiguous area and detected the movements within every layer following the principles described in the above sections. Figure 20B shows

the recorded positions and the routes of tissue movement in the first half of the designated movement task, which is from neutral standing to a full lumbar flexion posture. Further calculations, including moving distance, boundary gliding and layer deformations, were carried out based on the data displayed on this map.

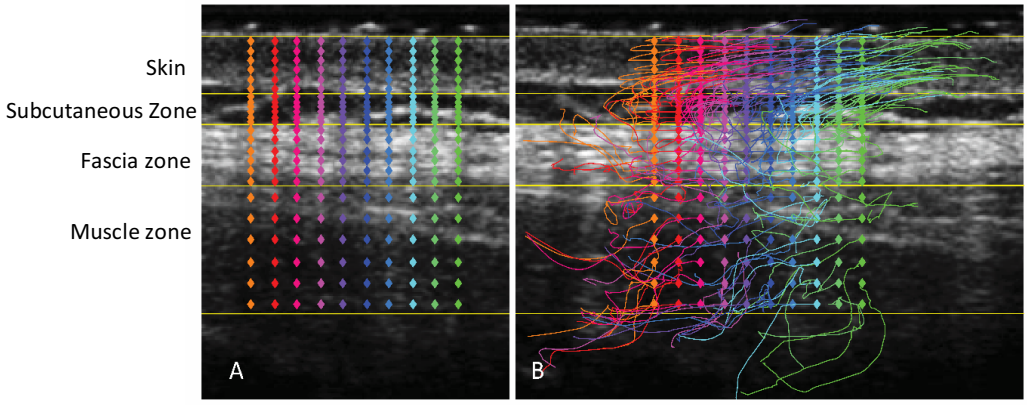


Figure 20. Demonstration of ultrasound tracking result.
A: an example of layer recognition with 240 points of interest.
B: an example of results of 240 tissue movement routes during the lumbar flexion task.

4.4.1.5.2 Problem of scanning during movement and probe holder design

Performing ultrasound scanning during the designated movement task was a challenge. The thoracolumbar area has a natural lordosis in most participants when standing, and it typically becomes kyphotic at the end of range lumbar flexion. Maintaining skin contact between the transducer probe and the skin was difficult due to this large amplitude movement and deformation of the surface of the thoracolumbar area. The other issue was the curve, and variable activation, of the erector spinae muscle. The transducer probe was very likely to slide to either the lateral or medial side during the movements when the ultrasound gel was applied. Maintaining the ultrasound beam on the same plane was therefore difficult.

To overcome this potential confounder, an ultrasound probe holder frame was made to help prevent the lateral and rostral translation and swing of the ultrasound during the lumbar flexion movement (Figure 21). This design ensured image quality, by minimising this lateral translation and swing. Scanning with the probe holder frame enabled the investigator to maintain the transducer probe in position without compressing the skin which would become an uncontrolled force input to the soft tissue that may limit tissue movement and

affect the natural deformation of tissues. Avoiding probe compressing can also reduce compression artefacts in ultrasound images. Using the probe holder also prevented from losing skin contact. By attaching the probe to the frame, a gap between the transducer and the skin was created. Ultrasound gel was filled in the gap to ensure the ultrasound beam was able to penetrate at all times. Because ultrasound gel has better deformation properties, the gel would deform to fit body contours during movements. Therefore, having the gap filled with gel on the probe holder overcame the issue of losing contact caused by lordosis-kyphosis transforming (Figure 22).

Although the innovative design of the transducer probe holder successfully navigated some probe movement challenges, the size of the holder being too big was another issue. It occupied too much space on the lower back and therefore affected the placement of EMG electrodes. Apart from this, having a solid object with such a big contact area on the skin was considered as a potential uncontrolled factor which may influence the results. Thus, a second version of the probe holder was made to solve this issue. As demonstrated in Figure 23, the new probe holder is narrowed down to about half of the original width (from 9 cm to 5 cm). This version was eventually used in all data collection of the present project.

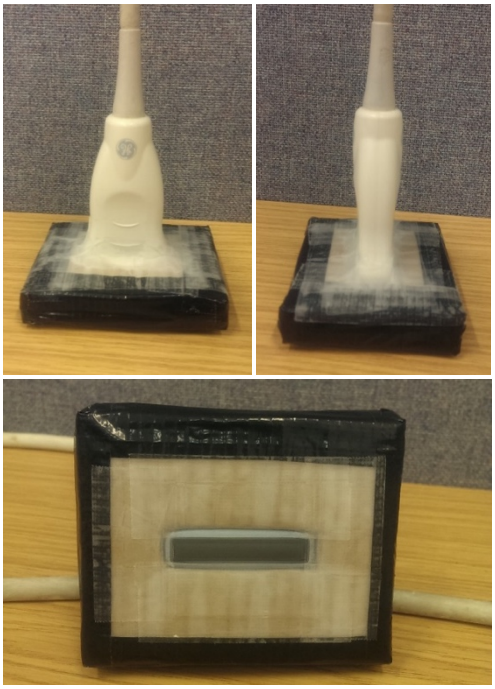


Figure 21. Ultrasound probe transducer with a customised probe holder frame (version one).

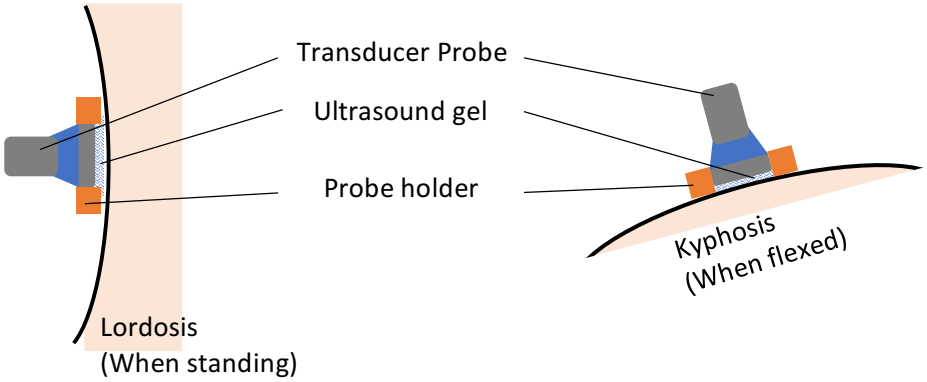


Figure 22. Demonstration of overcoming the difficulty of negotiating varying spinal curves by using a transducer probe holder and gel

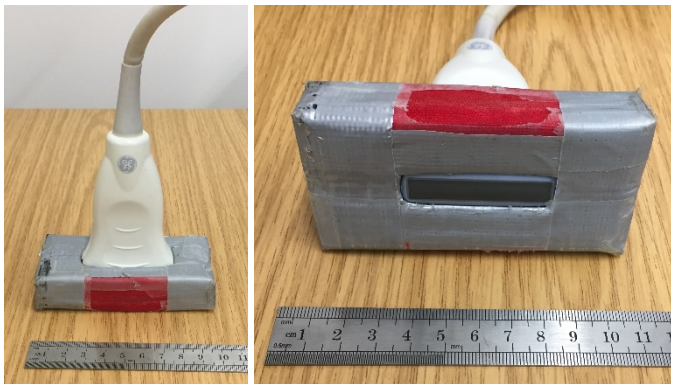


Figure 23. Ultrasound probe transducer with a probe holder frame.

4.4.1.6 Test-retest reliability

In order to ensure the method described in the above sections were able to provide a consistent result, a test-retest reliability study was conducted. Ultrasound videos of known orientation and position were taken of 9 asymptomatic participants (male and female, aged 27.3 ± 2.04, BMI 22.98 ± 3.10) while performing velocity-guided lumbar flexion with and without taping. Every participant performed the same movement twice for each taping conditions. The semi-automated algorithm developed in this PhD project was applied to process all cine clips. Reliability was assessed using the intra-class correlation coefficient ($ICC_{2,1}$) between the same movement performed in different time, while limits of agreement (LOAs) were calculated and systematic differences tested for with a Student's t-test.

The variable used for reliability testing was mean thoracolumbar tissue movement. These values were mean movements across all target positions shown in Figure 20B. A single movement was extracted from the distances between the start and the endpoints of each target. As shown in Table 4, the mean movements of thoracolumbar tissue, during lumbar

flexion before and after taping showed strong within-subject reliability both when subjects were moving with and without tape applied (ICC = 0.82) and with Kinesio- taping applied (ICC = 0.82). No significant systematic differences were found (No tape: t = 1.00, df = 8, p = 0.32; with tape: t = - 0.13, df = 8, p = 0.90). Intra-observer analysis revealed acceptable LOAs for both measurements when subjects were taped and not taped (Figure 24).

Table 4. Intra-class correlation coefficient and limits of agreement

	Scan 1	Scan2	p	ICC[a]	MEANdiff[b]	SDdiff[c]	L.LOA[d]	U.LOA[e]
No tape	2.15 ± 2.76	1.91 ± 2.30	0.32	0.82	0.23	1.97	-3.63	4.09
With tape	1.76 ± 1.78	1.78 ± 2.53	0.90	0.82	-0.02	1.69	-3.33	3.29

a: ICC, intra-class correlation coefficient; b: the mean difference between measurements; c: standard deviation of the difference between measurements. d, e: lower and upper limit of agreement. (Figure unit = pixels, 1 pixels = 0.12 mm)

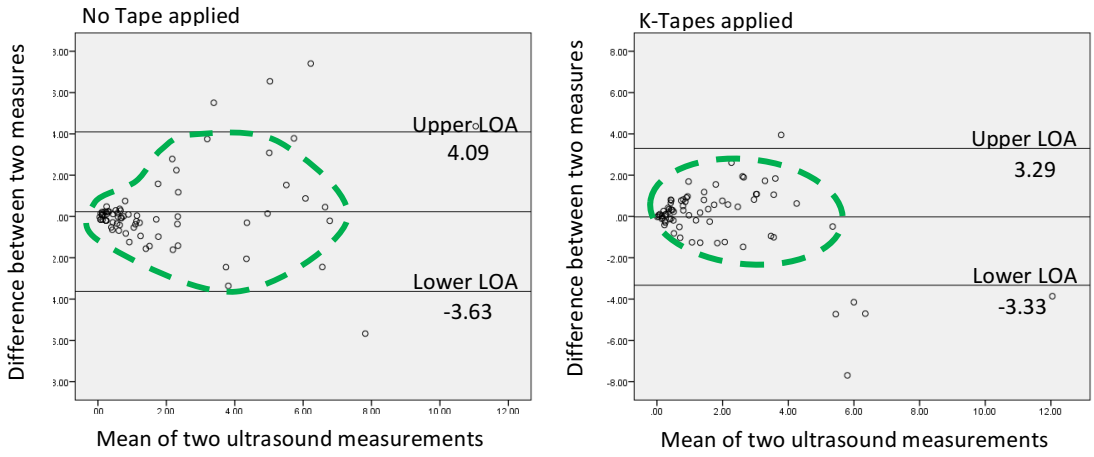


Figure 24. Limit of agreement plot – comparison of two scans in tape and no tape conditions (unit: mm)

4.4.2 Image-based measurements validation using phantom tests

Apart from the reliability test based on the images collected from human participants, validation experiments were carried out on gelatine and meat phantoms. Although the ultrasound scanning method was developed based on the images collected from the real human body and the results were found to be reliable, testing the same procedure on phantoms enabled comparison between ultrasound-based measurements and direct measurements. This ensured all variables extracted from my analysis were authentically representing the phenomena that this project aimed to observe.

Two types of phantoms were used in the validity study. One gelatine phantom was made for length measurement validation, and the other phantom was made by a few layers of fresh meat to simulate tissue layers. Details of these experiments were as described in the following sections.

4.4.3 Gelatine phantom

A gelatine brick, with a tunnel filled with ultrasound gel, was made as a validation phantom. Due to density difference, the tunnel can be easily identified by vision. A metal pin was used as a tracking target as it has high reflective properties and is easily distinguishable in the image (Figure 25). Ultrasound images were captured when the metal pin was inserted into the gelatine tunnel while a ruler was used to measure the insertion distance. The images were processed with the algorithm in order to test if algorithm outputs matched direct measures for this simple movement.

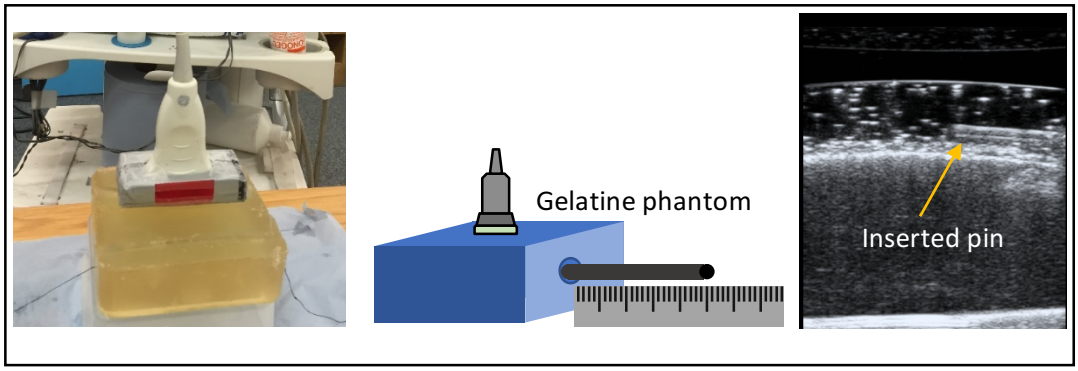


Figure 25. Gelatine phantom for ultrasound validation

Measurement results of metal pin movements using an external clipper and computer-based image processing are shown in Table 5. The two measurements showed a strong correlation ($r = 0.99$) and no significant systematic differences was found. Agreement between two measurement tools was analysed by Bland-Altman plot, which revealed acceptable LOAs (90%) for both measurements (Figure 26).

Table 5. Results of three measurements of gelatine phantom validation comparison (unit: cm)

	Values	p[a]	$ICC_{2,1}$[b]	MEANdiff[c]	SDdiff[d]	L.LOA[e]	U.LOA[f]
Ultrasound machine measurements	2.25 ± 0.54						
MATLAB measurements	2.29 ± 0.53	0.99	0.99	0.019	0.038	-0.056	0.094
External measuresments	2.30 ± 0.55						

a: P value of T-test of systematic error check; b: ICC, intra-class correlation coefficient; c: mean differences between measurements; d: standard deviation of differences between measurements. e, f: lower and upper limit of agreement

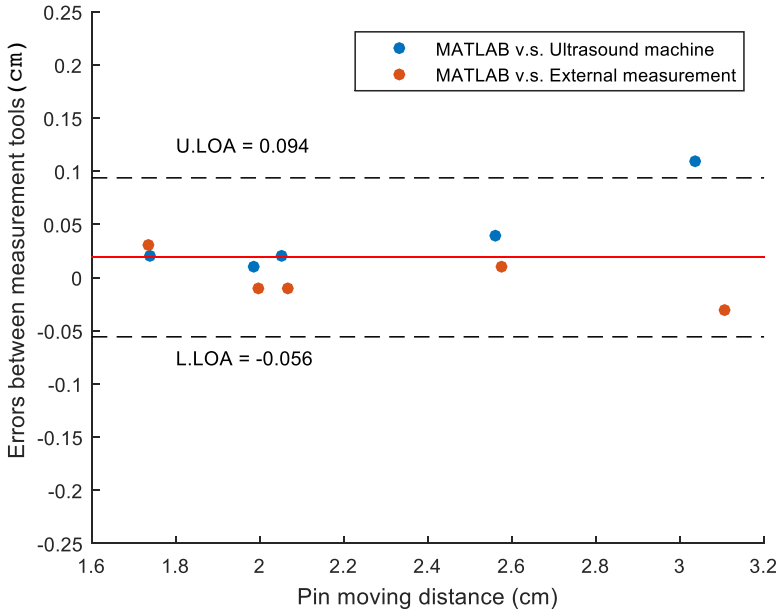


Figure 26. Bland-Altman plot for validation of external measurement compared to computer-based image measurement (unit: cm)

4.4.4 Meat phantom

Although the built-in ultrasound measurement tools have been extensively used for diagnostic purposes and the accuracy has been validated it the last experiment, it would be ideal to test if the movements estimated from ultrasound images match the direct measurements from the object. In order to stimulate 'layer gliding' of soft-tissues, a three-layer stacked fresh meat phantom was made for validation data collection. Three slices of meat were stacked, and ultrasound gel was interposed between the layers. Solid wooden frame clamps, with motion capture markers attached, were used to hold each layer of meat and to guide the movements. When capturing the data, the central layer was pulled steadily

and slowly, while motions of the layers and the transducer probe were recorded synchronously with ultrasound images (Figure 27).

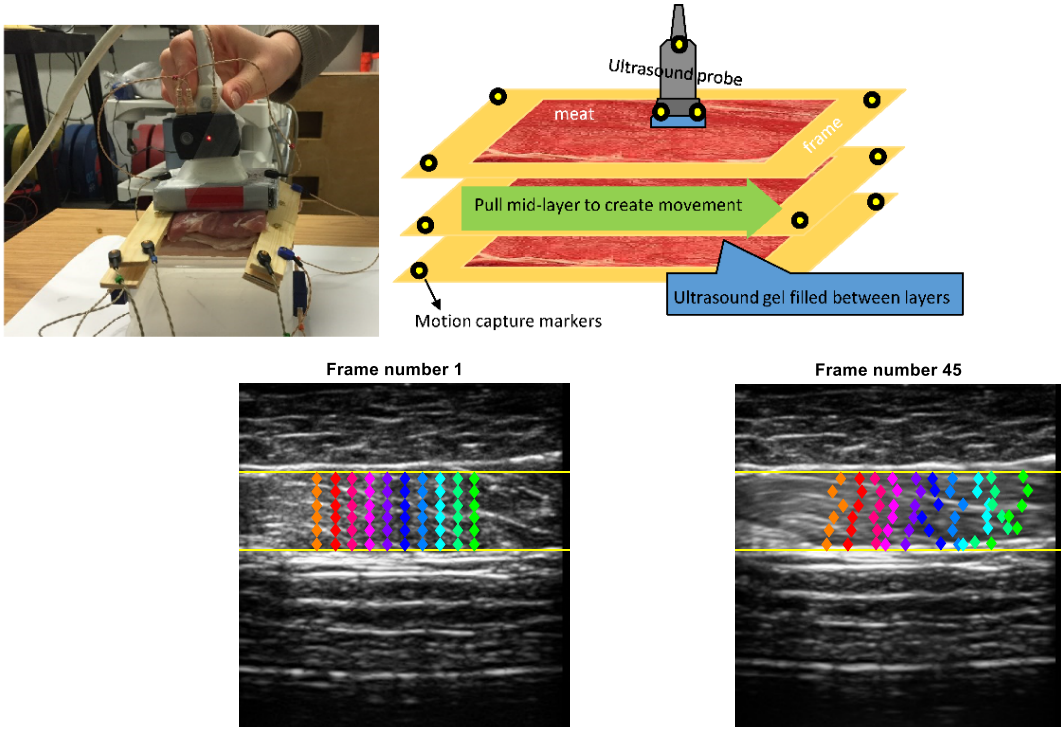


Figure 27. Meat phantom for ultrasound validation
Top: meat phantom, ultrasound probe and kinematic marker settings
Bottom: ultrasound image in frame 1 and 45 including the tracking results

Results of movement distance measured using the motion capturing system and ultrasound-based image measurements are shown in Table 6. Two measurements showed a strong interclass correlation coefficient ($ICC_{2,1}$ = 0.86). However, a significant systematic differences between two measurement tools was found ($p < 0.01$). Ninety-five percent limits of agreement between two measurement tools was plotted in a Bland-Altman plot, which is helpful for examining consistency and systematic errors between the two measurements (Figure 28).

Table 6. Results of ultrasound and motion measurements of meat phantom validation comparison (unit: mm)

	Values	p[a]	$ICC_{2,1}$[b]	MEANdiff[c]	SDdiff[d]	L.LOA[e]	U.LOA[f]
Ultrasound measurements	4.44 ± 3.91	0.01	0.86	7.74	2.01	3.80	11.67
Kinematic measurements	12.18 ± 3.63						

a: P value of T-test of systematic error check; b: ICC, intra-class correlation coefficient; c: the mean differences between measurements; d: standard deviation of the difference between measurements. e, f: lower and upper limit of agreement

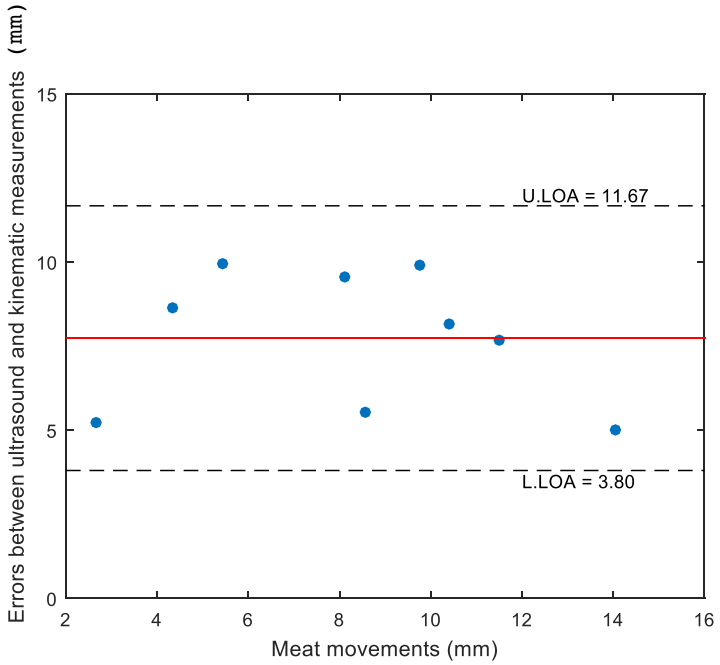


Figure 28. Bland-Altman plot for validation of ultrasound compared to kinematic measurement

Above two validity experiments revealed a potential error of the assessment method and processing algorithm. The first validity result retrieved from a gelatine phantom and solid pin movements was acceptable, as potential errors were within a range of 4 mm, and no significant systematic difference was found. Conversely, a systematic error was detected in the second mimicking experiment. To ensure the methodology development was valid, following parameter was considered.

Firstly, movement speed was not well controlled in the meat phantom study. The image was a blur during the movement (see Figure 27, bottom right), so the automatic tracking algorithm failed to track all the movements. Secondly, a considerable amount of deformation occurred in the middle layer of meat phantom during motion capture. The meat was pulled from one side, and the most deformation was found in the junction between clamps and the

meat layer. Therefore, measured movements in the motion capturing system are consistently larger than the movements detected by the ultrasound tracking.

A revised version of the phantom was made to ensure a better control of the potential variables which causing inaccuracies. A larger cut of pork belly meat with skin on was used as the 'base'. A pocket was cut between two layers of muscles to allow artificial movement creation, motion capturing markers were placed on the meat base, ultrasound probe and the clamps of the moving layer (Figure 29A). A plastic bag interposed with a thin layer of meat and water-based gel was placed in the meat pocket on the base (Figure 29.B). Two pieces of wooden straps and metal clamps were placed on one side of the plastic bag for pulling movement and motion capture. The plastic bag used in this experiment was made by a piece of thicker and harder material. Therefore, deformation of the moving layer was ignorable. Ten sets of ultrasound and kinematic data were collected in this revised version of the experiment.

The results of movement distance measured using the motion capturing system and ultrasound-based image measurements are shown in Table 7. Mean layer moving distance along a horizontal line across ten trials was 25.10 ± 2.55 measured from the ultrasound algorithm, and 24.84 ± 3.82 measured from kinematic data. Two measurements showed a strong interclass correlation coefficient ($ICC_{2,1}$ = 0.82), and no systematic differences between two measurement tools were found (p = 0.37). A Bland-Altman plot was used to reveal the potential error and limits of agreement between two measurement tools (Figure 30).

Table 7. Results of ultrasound and motion measurements of meat phantom validation comparison

	Values	p[a]	$ICC_{2,1}$[b]	MEANdiff[c]	SDdiff[d]	L.LOA[e]	U.LOA[f]
Ultrasound measurements	25.10 ± 2.55	0.37	0.82	-0.26	2.33	-4.82	4.31
Kinematic measurements	24.84 ± 3.82						

a: P value of T-test of systematic error check; b: ICC, intra-class correlation coefficient; c: the mean difference between measurements; d: standard deviation of the difference between measurements. e, f: lower and upper limit of agreement

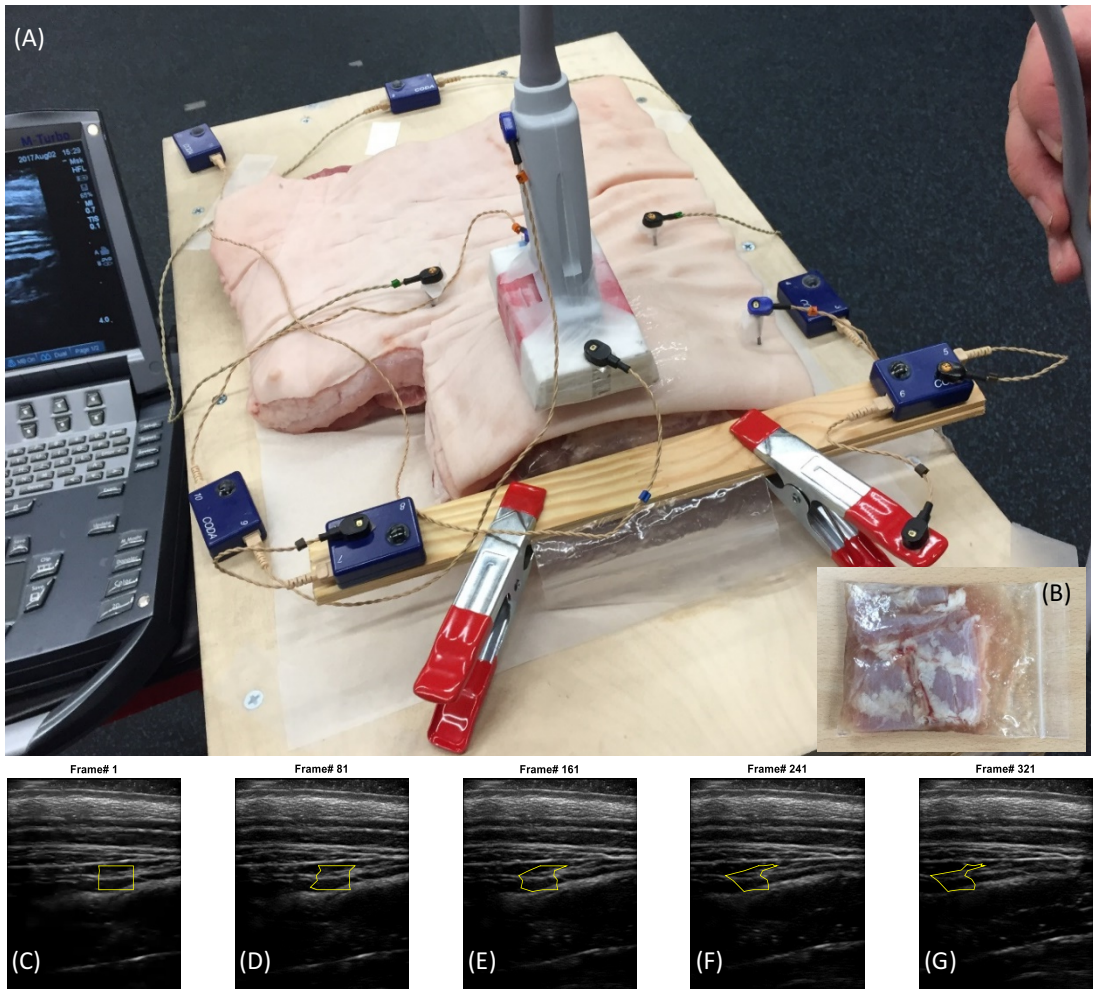


Figure 29. Meat phantom for ultrasound validation

Top: (A) meat phantom, ultrasound probe and kinematic marker settings (B) the moving layer used in the phantom

Bottom: ultrasound image in frame 1, 81, 161, 241 and 321 including the tracking results (frame rate: 30Hz).

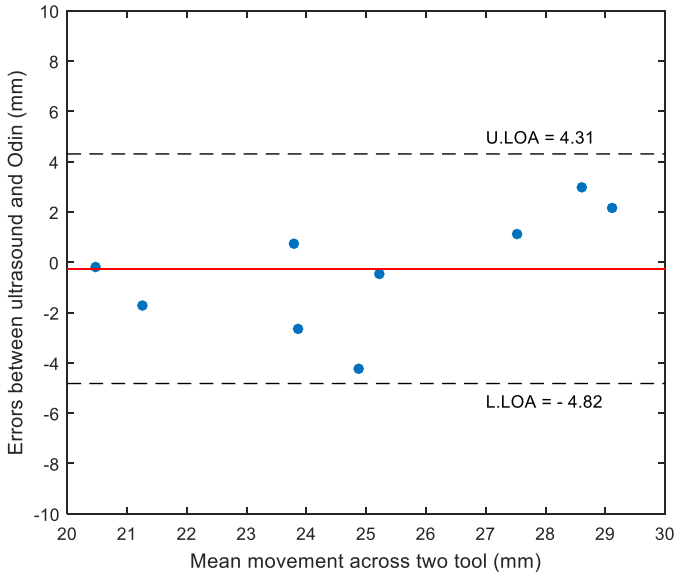


Figure 30. Bland-Altman plot for validation ultrasound and kinematic (Odin system) measurement

4.4.5 Electromyography measurements

4.4.5.1 Rationale for measuring electromyography

One proposed mechanism of KT is to produce concentric tension on the skin, which may stimulate the skin and connective tissue to facilitate small immediate increases in muscle strength. Facilitated muscle activity and improved muscle alignment might contribute to marginal increases in muscle strength and have been suggested as additional hypotheses (Kase et al., 2003). Two studies reported positive outcomes in measures assessing strength. Fu et al. (2008) examined the effect of KT on muscle strength in healthy collegiate athletes. One statistically significant result was reported for the concentric contraction of the quadriceps at 12 hours after taping, with tape still on the thigh, but no statistically significant results were reported for the seven other measures of peak torque. Hsu et al. (2009) assessed changes in lower trapezius muscle strength using a hand-held dynamometer, before and after taping application. The result of studies in muscle functions appear to be beneficial, or at least have a small beneficial effect on strength. However, the results from the previous study are either unclear or trivial for measurements of strength. Even though the increase in muscle strength was found after receiving KT, monitoring muscle activity instead of measuring strength was a necessary approach to discover the actual mechanisms behind KT technique as strength sometimes is directly related to muscle activations.

4.4.5.2 Current development of EMG electrode types

There are two main types of electromyography electrodes, namely skin surface electrodes and fine wire electrodes. Among these, skin surface electromyography electrodes are the most widely used due to their non-invasive application. Surface EMG electrodes are used in most kinesiology studies, which requires an in-vivo measurement tool with minimal influence on body movement. Therefore, several different skin surface electrode application choices, such as monopolar, bipolar and low or high-density arrays have been developed to fit different research needs. These methods have individual applications as well as advantages and disadvantages. For instance, conventional bipolar sEMG is commonly used for monitoring large surface muscles in movement studies; HD-sEMG enables measurement of muscular activity at the motor unit level; while fine wire EMG is used as a tool to obtain information from smaller units, such as muscle fibres and the membrane (Drost et al., 2006).

4.4.5.2.1 Fine wire EMG

Measuring muscle activity with fine wire insertion is the most invasive EMG technique. Despite its invasive challenge, fine-wire EMG is suitable to monitor neuro-activity down to a

muscle fibre level, which provides details of motor control. It is therefore applied in investigating the firing characteristics of motor units (MUs) (De Luca et al., 2014, Drost et al., 2004, Hermens et al., 1992), while motor neuron activities which are difficult to measure using surface electrodes. Fine-wire EMG monitoring is also used for neurological and neuromuscular diagnoses. However, this type of EMG collection method was considered not suitable for this project, because such invasive method can be dangerous during movement. This concern, therefore, decreased its feasibility and would have likely reduced the chances of ethical approval.

4.4.5.2.2 Surface EMG

Surface electromyography (sEMG) is a suitable way to collect information from large superficial muscles. It is, therefore, widely used in the field of biomechanics, rehabilitation and sports (Lyons et al., 2003, Yoo et al., 2014). The most attractive benefit of sEMG is easy and quick handling. It has relative low hygienic concerns because it is usually stuck on the skin surface with low allergic tapes (Konrad, 2006). sEMG has been used to study normative muscle activation values in a variety of populations in living-related or sports-specific movements. It, therefore, guides the rehabilitation strategy by providing information of muscle activation in various exercises and movement tasks (Boudreau et al., 2009, Delmore et al., 2014). It is also a valuable tool to diagnose muscle dysfunctions and damage (Felici et al., 1997, Merletti and Parker, 2004). However, sEMG still has some limitation, such as not being able to measure deeper muscles and potential cross-talk (Konrad, 2006, Hermens et al., 1999). For example, other physiological signals can also be detected by the surface electrodes such as electro-cardiac activity. The preparation of placing electrodes over the muscle belly of the target muscles needs to be carefully following some standard guidelines such as *Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles* (SENIAM)(Hermens et al., 1999). Careful palpation of muscle borders and testing of contraction using resisted exercises is also critical to confirm accuracy as per recommended guidelines.

4.4.5.2.3 Multi-channel electrode arrays

Multi-channel sEMG electrode methods enable the collection of both temporal and spatial EMG activity and extend the application of traditional bipolar sEMG methods which are limited by the relatively small detectable range under two electrodes. Measuring muscle activities using a grid of surface electrodes enables the description of an approximation of overall muscle activity in the area underlying the sensors (Vieira et al., 2010). This is a later developed sEMG technique in order to fill in the gap between conventional sEMG and needle

EMG (Drost et al., 2006). Data collection usually achieved by applying electrodes as high-density arrays across or along the muscle (Drost et al., 2006, Farina et al., 2003, Merletti et al., 2003). This technique is able to collect detailed samples of muscle activities at motor unit (MU) level from the surface electrodes (Merletti et al., 2003, Stegeman et al., 2000). Multi-channel EMG arrays should be considered as a strong tool because this technique enables collecting MU information, which usually requires a needle electrode, via non-invasive electrodes (De Luca et al., 2014, Drost et al., 2004, Hermens et al., 1992).

At present, there are still some challenges needing to be solved before applying this EMG technique as a standard clinical neurophysiological assessment tool. It is important to examine muscle activity at MU level, but the analysis of single MU firing patterns and MU characteristics is still too complicated and time-consuming (Drost et al., 2006). More, and validated, automated analyses are crucial to overcome this problem.

4.4.5.3 Choice of electrode Decision

Paoloni et al. (2011) conducted a study examining whether KT changed the electromyography characteristics in patients with LBP with traditional bipolar electrodes. This study, only able to demonstrate that the flexion-relaxation phenomenon reappeared in one-third of patients after receiving treatments of exercise and taping. This finding may be considered to be a consequence of active restoration of lumbar muscle functional status. However, some people with no LBP can also fail to achieve the flexion-relaxation phenomenon. Thus, the finding of this study is inadequate to explain the mechanism of clinical improvement after KT. Therefore, a tool to provide more information about lumbar muscle activities when performing the experimental task with and without KT is required.

Previous studies of the dynamic movement reported that linear electrode arrays can be representative of the entire muscle and it is sensitive enough to track fast changes during the movement (Farina and Falla, 2008, Farina et al., 2003, Merletti et al., 2003). Several previous studies have also researched the regional distribution of EMG activity using this method, and the outcomes were relevant to fatigue and delayed-onset muscle soreness predominating (Hedayatpour et al., 2008, Kleine et al., 2000, Staudenmann et al., 2014). It is therefore a potential method to discover plenty of characteristics of myoelectric signals in the area of the sensor in vivo, such as the distribution of muscle fibre types, the architecture of the underlying muscle fibres, the location of the motor endpoints, the distribution of motor units and the nature of the demands being placed upon the muscle (Staudenmann et al., 2014, Vieira et al., 2010, Watanabe et al., 2014).

The aim of using multi-channel electrode array in the present project was to discover the neuromuscular characteristics that may link KT mechanisms to observed clinical effects. The most important goal of measuring EMG was to understand if any EMG difference between the conditions of with and without KT could explain differences observed using ultrasound.

4.4.5.4 EMG data acquisition

4.4.5.4.1 Introduction to the machine and settings

Exploring para-spinal activation patterns and area activation in a thoracolumbar area with and without KT is the key goal of the present project. A 64-channel EMG system (REFA64, TMSi, Netherlands), which was available in the Human Performance Laboratory, was used to collect EMG data (Figure 31). This system has an auxiliary input which allowed for the simultaneous, synchronised collection of other types of signals. This input/output availability was particularly useful for synchronisation between the ultrasound and motion capture systems.

A linear multichannel EMG arrays using the micro-electrodes, which are available with the REFA system (as described in Figure 31), was applied to the thoracolumbar area of each participant (Figure 32). Sixteen monopolar Multi-channel EMG signals were collected from the erector spinae instead of one bipolar single-channel on each side. These settings enabled more potential analytical approaches. For example, these monopolar electrodes can be paired to 8 bipolar channels, and at the same time can be processed as activation mapping. Two columns of EMG electrodes, eight in each, were placed 1 cm away from the spinous processes. The rostral end was placed beside L1/T12, and the caudal end was placed beside L5/S1, the other six were dispersed equally the between two ends. (Figure 32).

These sensors have a 1 mm silver-silver chloride (Ag/AgCl) sensing area. The small sensing area is suggested to minimise crosstalk and motion artefact. Through a series of experiments, a method to fix these sensors to the skin was developed in the Human Performance Laboratory. All the sensors were attached using a combination of hypoallergenic tape (Hypafix, BSN Medical) which was in contact with the participant, backed with double-sided adhesive tape in contact with the electrode. The sticky tapes were punched with 5mm holes for skin contact. A syringe was then used to apply a small amount of conductive gel to the sensor surface. This method was customised from previous projects acquiring lumbar and hamstring EMG (Daly, 2017).

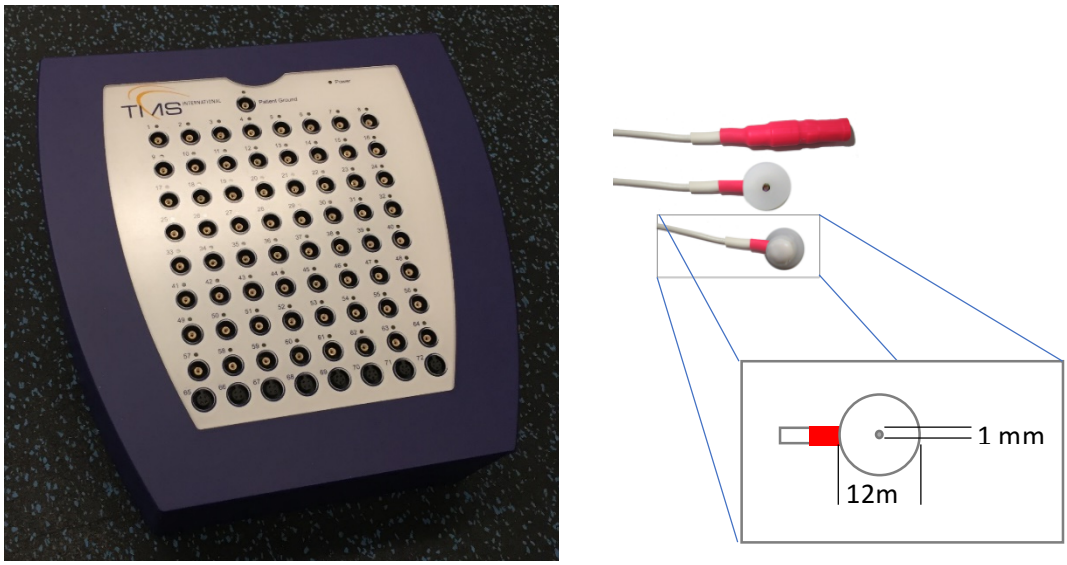


Figure 31. The REFA 64 channel system

Left: TMSi Refa 64 Singal amplifier and analogue / digital converter
Right: TMSi 1 mm silver-silver chloride (Ag/AgCl) EMG electrode

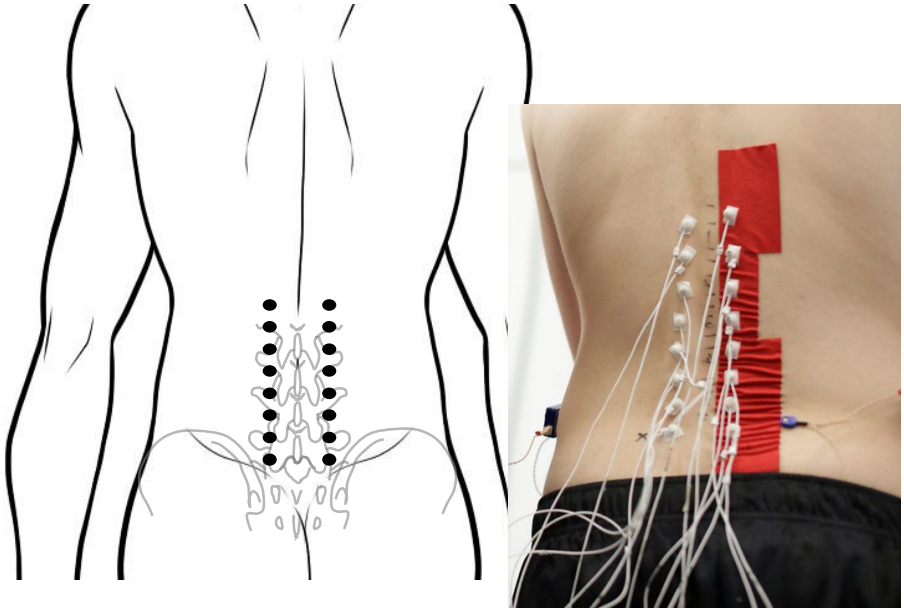


Figure 32. EMG electrode placements

4.4.5.4.2 Data acquisition

All surface EMG signals were collected at a sampling rate of 2048 Hz using PortiLab software (TMSI, Netherlands) on a separate PC via a two-way glass fibre connection. Within the REFA system, monopolar signals are amplified against the mean of all connected channels. All EMG cables were individually shielded to ensure minimum interference from ambient signals or motion artefact. All collected signals were visually checked during data collection and made

adjustments to avoid any signal interference due to poor contact with the skin or trunk movements. The subject ground electrode was attached to the olecranon of one elbow. Signal quality was checked visually in advance and during data acquisition.

4.4.5.5 EMG Data processing

Details of EMG signal processing method are given in this section. The first part describes current standard pre-processing methods including filtering, rectification and smoothing processes, and the second part describes advanced analysis and feature extraction, such as amplitude analysis, frequency and wavelet analysis and activation mapping.

4.4.5.5.1 Basic EMG signal processing techniques

4.4.5.5.1.1 Signal preparation

EMG data were initially converted from the TMSi format into a MATLAB matrix. A MATLAB based GUI interface software was developed to convert and retrieve synchronised chunks of data (Figure 33). This programme allows investigators to preview signal quality and to check synchronisation status. Before signal processing, the length of trimmed data was also compared to the motion data in order to ensure no synchronisation error occurred. Initial EMG data, which began collecting before motion capture onset, and final sample sections, which were collected after motion capture finished, were discarded according to the TTL synchronisation signals received from the motion capture system (see *8 in Figure 33).

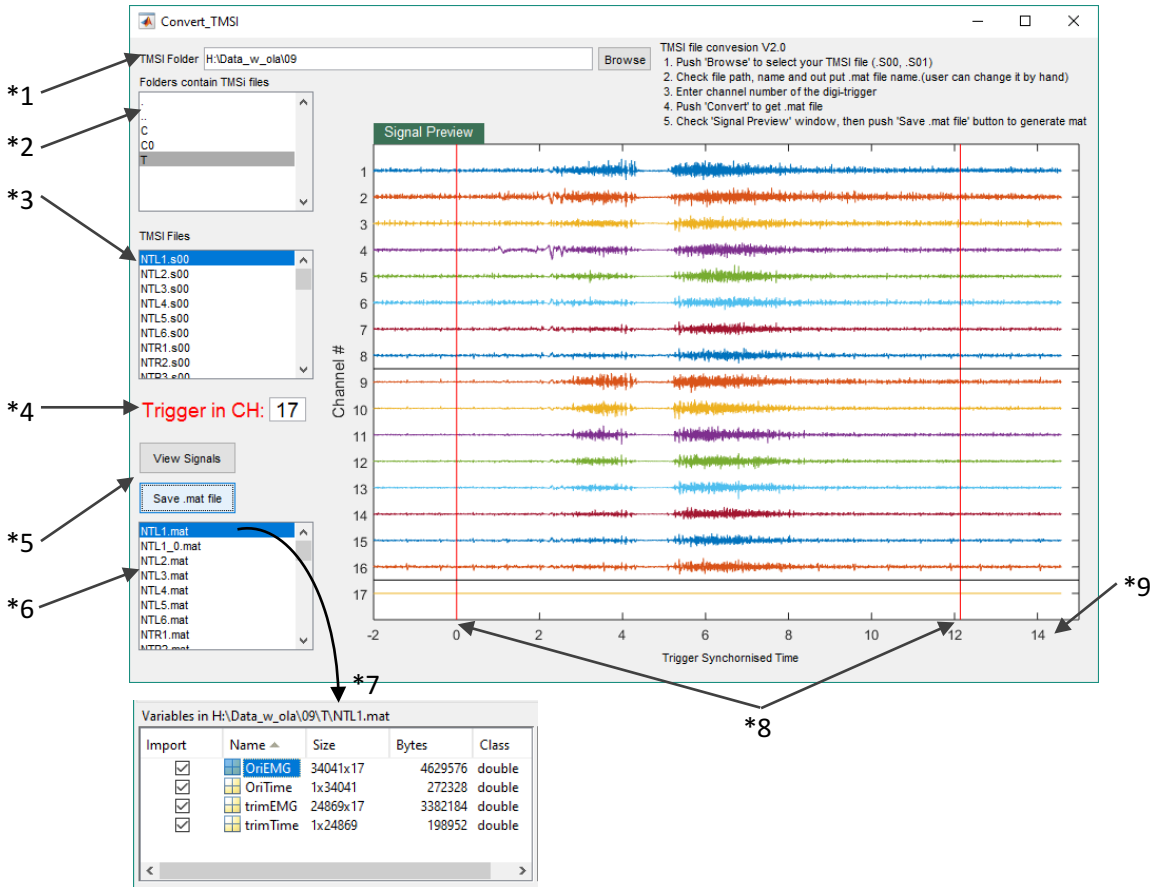


Figure 33. Customised GUI software for EMG signal conversion and post-collection synchronisation

**1 Master directory indicator*
**2 subfolder indicator*
**3 List of TMSi EMG files (.s00 format)*
**4 Synchronisation signal indicator*
**5 Control panel*
**6 List of converted files (.mat format)*
**7 an example of software output – contains original data and synchronised data*
**8 Synchronisation marks*
**9 Time axis has been adjusted as per synchronisation marks*

4.4.5.5.1.2 Signal filtering

sEMG filtering commonly occurs during digital data filtering (Kamen and Gabriel, 2010). A band-pass filter with a range of 10 to 500 Hz was used to filter all sEMG signals in this study. A 10 Hz high-pass filter is recommended by the International Society of Electromyography and Kinesiology in order to successfully remove the noise associated with electrodes and wire movement. By visual examination of signal power spectrums, which were generated by performing a Fast Fourier transform, a 50 Hz ambient electrical interference was detected in all EMG data collected from Human Performance Laboratory (Figure 34.) A notch filter of 50 Hz was therefore applied to remove this interference. The effects of filtering were visually examined by reviewing power spectral density, before and after signal filtering. This step

aimed to remove the 50-Hz ambient electrical interference and low-frequency interference (Figure 35). If the filtering successfully removed noise from muscle activation, the data were further analysed. Data were removed from further analysis if motion artefact adversely affected signal quality, which usually appeared as a low frequency, high amplitude signal - or where data was missing due to detached or damaged sensors.

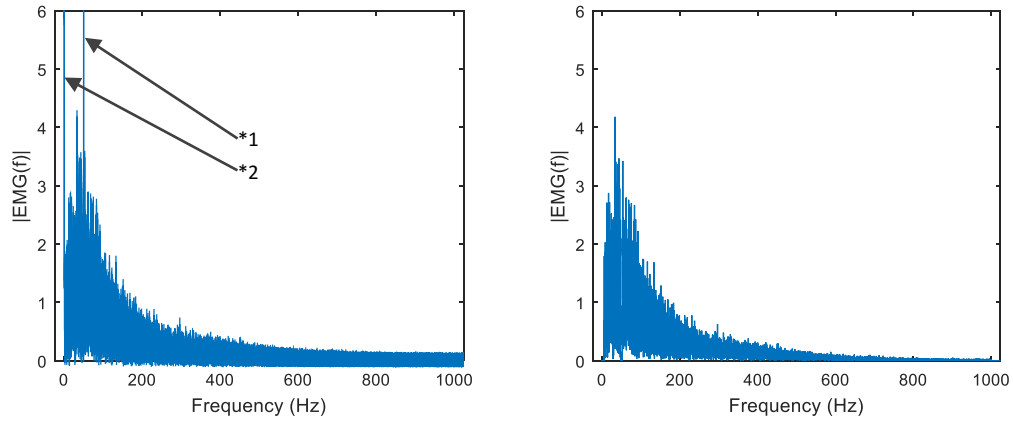


Figure 34. Example power spectrums demonstrating electrical interference noise
Left: EMG signal with interference; Right: EMG signal without interference
**1 50 Hz ambient electrical interference*
**2 low-frequency interference*

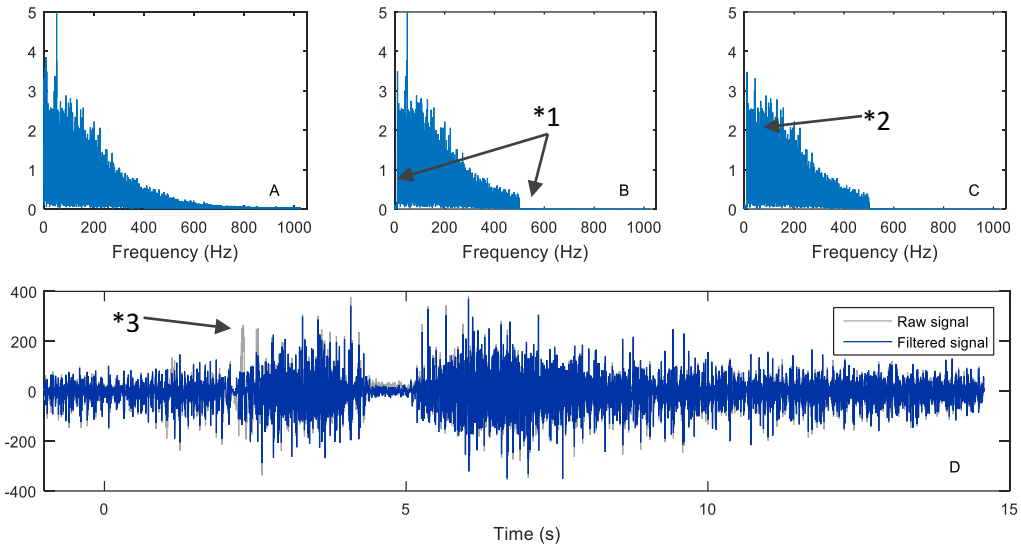


Figure 35. Demonstration of comparison of raw and filtered EMG signals
A: a power spectrum of raw signal
B: power spectrum of a band-pass filtered signal
C: power spectrum of a 50 Hz notch filtered signal
D: Comparison of raw and filtered signal
**1: Power of low/ high-frequency noise has been reduced*
**2: Power of 50 Hz interference has been reduced*
**3: low-frequency interference has been removed after filtering*

4.4.5.5.2 Advanced signal processing and analysis

Although the raw EMG signal already contains important information and may serve as an initial check and the first objective documentation of the muscle innervation, the studies of "off-on" and "more-less" characteristics of EMG signals contain more important understandings of the neuromuscular control (Konrad, 2006). Therefore, further quantitative assessments were performed to derive muscle activation information during the tests.

4.4.5.5.2.1 Amplitude analysis

Quantitative amplitude analysis, which is targeted in most cases of EMG specific signal processing steps and believed to increase the reliability and validity of findings (Konrad, 2006), was applied to the present project to enable important understandings of the neuromuscular control during the experimental task with or without taping. As per international scientific recommendations (ISEK, SENIAM), some of the well-established processing methods were used as post hoc processing before extracting outcome measurements. Details of these processing methods were outlined in this subsection.

4.4.5.5.2.1.1 Full wave rectification

Each EMG signal was rectified, after removing any baseline offset or shifts. Raw sEMG signals represent the level of de- and re-polarisation of the muscle fibres membranes. Consequently, the raw sEMG typically has corresponding positive and negative values. All negative amplitudes were converted to positive amplitudes in the first step of full-wave rectification. The negative spikes were moved up to positive or reflected around the baseline. Apart from an easier reading of the signals, the main benefit of full-wave rectification is that common standard statistical procedures such as mean, peak or max value and area calculation, can then be applied to the curve, while raw EMG signals have an average value of approximately zero. Half wave rectification, which is a method of discarding all negative amplitudes in order to extract statistical parameters, is an alternative method of signal rectification. However, this method may cause information to be lost. Thus, it has not been used in the present study. Figure 36 gives an example comparison of full-wave rectification and half wave rectification.

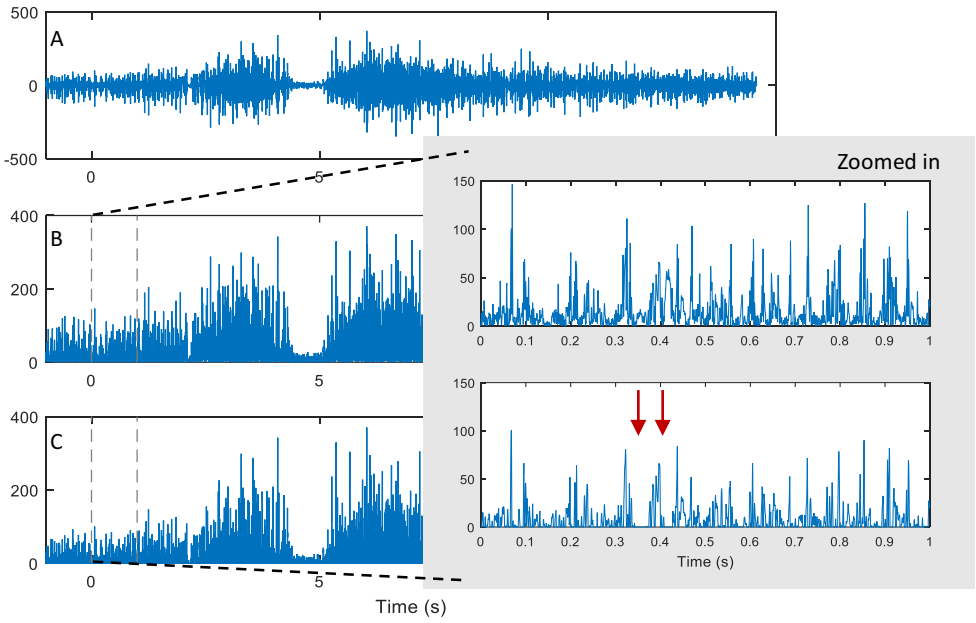


Figure 36. Demonstration of two sEMG rectification methods

A: Filtered EMG signal
B: Full wave rectification
C: Half wave rectification
Right: zoomed in 1-second window, red arrows showed information lost in half wave rectification

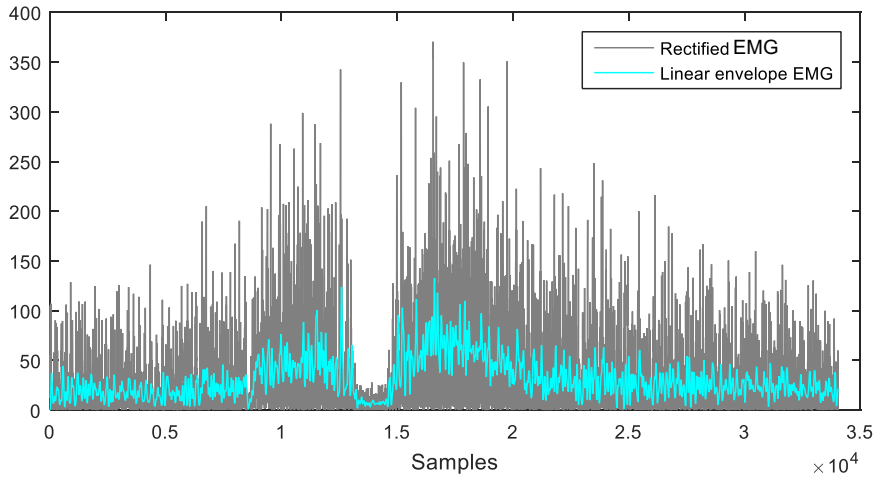


Figure 37. Demonstration of linear envelope processing

4.4.5.5.2.1.2 Smoothing and liner envelope processing

A raw EMG burst cannot be reproduced a second time with exactly the same shape because the way the motor unit action potentials is arbitrary, and the actual set of recruited motor units continuously changes within the motor unit diameter (Konrad, 2006). The non-reproducible part of the signal, which is the steep amplitude spikes, was cut away and minimized by applying digital smoothing algorithms which outline the mean trend of the

signal. As shown in Figure 37, the EMG signal then received a 'linear envelope'. This was performed by smoothing all signals with a low pass filter – in this case, a zero-lag fourth-order low-pass Butterworth filter at 50 Hz (smoothing with a 20-millisecond constant) to create a linear envelope for each area (channel). This frequency was chosen because time constants higher than 25 to 30 millisecond introduce detectable delays and therefore can only be used on the mean amplitude (moving weighted average) rather than any timing relationship with other events (Merletti and Di Torino, 1999). The EMG data was ready for actual variable extraction after linear envelope processing (see next section 4.5 for the actual variable definition).

4.4.6 Kinematic measurements

Movement patterns and range of motion of lumbar flexion are common clinical assessments. These assessments often involve measurements in one or two dimensions. However, the lumbar movement is a complex movement involving a number of motion segments and intervertebral joints. Hence a system which enabled complex three-dimensional (3D) movement quantification was a potent tool to investigate KT mechanisms.

4.4.6.1 Different types of motion capture system

Three-dimensional kinematic data is a robust way, with acceptable reliability, to quantify and analyse multi-segment movement (McGinley et al., 2009). In the present project, kinematic data was required primarily to reference the lumbar posture during the experimental task; additionally, to discover if movement patterns changed when KT was applied in the thoracolumbar area, in comparison to the condition when participants had no taping applied.

'Motion capture' refers to a process of recording and measuring movements of humans, animals or any objects. It is presented in a numeric form that can be further applied (Dyer et al., 1995, Gabai and Primo, 2011). This technique has an extremely wide application; it is used in the field of arts, such as performance and animation. (McGinley et al., 2009). It also appears in medical research areas of psychology, orthopaedics, neurological disorders and sports medicine applications (McGinley et al., 2009).

A typical motion capture system includes a set of devices that able to track positions of objects through a movement, as well as software that can determine other feature parameters based on calculations. There are three main types of core capturing techniques are currently available, namely mechanical, magnetic and optical tracking system; each of these systems have certain advantages and disadvantages (Dyer et al., 1995).

Vision-based capturing is the most common type of systems in sports science research (Moeslund et al., 2006). The markers are placed on the object, and their location can be calculated by comparing the optical signals received by multiple infrared cameras. The markers attached to the object may operate either passively or actively (Richards, 1999). In passive systems, the markers are made with a retro-reflective material, which allows them to reflect the signal emitted from the cameras; in active systems, the markers themselves are emitting light, which is then captured by the cameras. Regardless of marker type, the optical signal received by each camera can only generate a 2D coordinate for each marker. In order to obtain location information of markers in a 3-d coordinates, the same optical signal needs to be received from two receivers located in different position. The positional information at each epoch can then be calculated and transferred into a 3D coordinate data (Bodenheimer et al., 1997, Moeslund et al., 2006). A growing interest has recently been shown by the biomechanics community in marker-less optical motion capture techniques (Ceseracciu et al., 2014, Sigal et al., 2010). As this technique is relatively new, there is still the need for validation and standardisation of the biomechanical models they comprise. Although some efforts at validation are made by the computer vision community, some issues still need to be solved before this method can be used in specific applications. For example, no standardised segmentation algorithm, which is well-developed in marker-based systems, has yet been developed (Ceseracciu et al., 2014). Description of functional joint angles, based on the precise anatomy of the subject and consistent with biomechanical societies' recommendations, has been so far neglected by marker-less system developers. Nonetheless, it is essential for the application of the latter in the clinical field (Ceseracciu et al., 2014). It was worth considering using marker-less systems in the present project due to its convenience. However, the active marker capturing system remains the primary choice for the present project. Because the marker settings and data processing procedure have been developed following recommendations of biomechanical societies and it was available in the Human Performance Laboratory (Charnwood Dynamics Ltd, 2014).

The quantification of observed movement in the present study was enabled by using the Cartesian Optoelectronic Dynamic Anthropometric motion system. Active infra-red markers were put on each participant's body according to validated protocols to collect the kinematic data (Monaghan et al., 2007). The markers attached to the surface of participant's skin on strictly specified anatomical landmarks served as a base to calculate joints centres: Trunk, pelvis, hips, knees and ankles. Data for the upper limbs were not collected in the present study, as they were irrelevant for the study aims.

The primary source of error in the kinematic measurements is anatomical misplacements of the infra-red markers on the participant's body. To accurately calculate joint rotation centres, participants' anatomical landmarks must have been identified with minimal error (McGinley et al., 2009). As with taping, EMG and ultrasound scanning, an extensive training period, a large amount of reliability data as well as my experience and occupation minimised the risk of the collected data being of poor quality.

4.4.6.2 CODA motion system introduction

Three-dimensional kinematic data were collected, while the participants performed designated movement tasks, by measuring lower limb, pelvic and trunk movements using a motion capture system. The CODA (the Cartesian Optoelectronic Dynamic Anthropometry) motion system (CX-1 units and software, Charnwood Dynamics Ltd., Leicestershire, UK) is an infra-red, active marker motion capture system which is available in Queen Mary University of London Human Performance Laboratory motion capture laboratory. Four CX-1 scanner units and one analogue to digital signal converter were used in the present project. This system uses information gathered from light emitting diode (LED) markers placed on body segments, to calculate their movements within a laboratory reference frame. The three-dimensional position of these LEDs was determined with an accuracy of ±1 mm by using the CODA motion analysis system. This system has the capacity to collect data on sampling rates up to 800 Hz. However, all data collected in the present PhD was collected at 100 Hz due to a bigger number of markers being involved (Charnwood Dynamics Ltd, 2004).

4.4.6.2.1 System calibration

Prior to any data collection, a Cartesian reference frame needs to be retrieved from all four CX-1 units in order to enable communication and to set up a lab coordinate system. Scanner units were placed around the capture area and orientated towards the centre of the space. An origin point which is approximately the centre of the data collection space was selected to establish the laboratory Cartesian frame. This was achieved through the placing a set of 3 to 5 LED markers at the origin point as well as along two of three axes of the coordinate base. Typically, a marker was placed to indicate the origin point; one marker was placed along the x-axis and another was placed indicating y-axis and direction. To save set up time, the number of markers can be reduced by two if the original marker were used as a mutual point when indicating axes and directions (Charnwood Dynamics Ltd, 2014). Figure 1 gives an example of 3-marker calibration and 5-marker calibration reference point set.

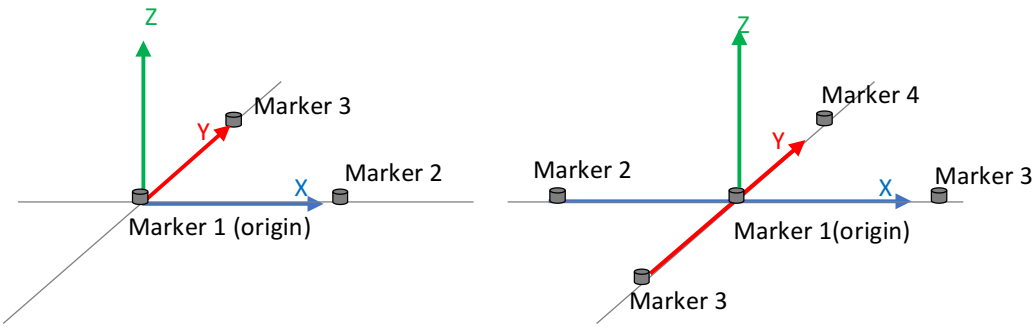


Figure 38. Examples of calibration marker sets
Left: a coordinate system defined by a set of 3 markers.
Right: a coordinate system defined by a set of 5 markers.

Each scanner unit has own scales, which is according to the distance between each scanner unit and the marks in three-dimensional space, and coordinate system. The calibration process offsets the location scales of all scanner units, which means the origin point was set to (x0, y0, z0), and aligns the orientation of coordinate system of each scanner unit. During data capture, the location of each marker was measured about the origin and described with x, y and z coordinates measured in millimetres. In order to maximise visibility with the data capture area, all scanner units were positioned on tripods encircling the area. It was imperative that these scanner units remained static following calibration, as any repositioning would invalidate the location of the origin and thus corrupt collected data. Therefore, if any repositioning of a scanner unit occurred, a recalibration was undertaken (Charnwood Dynamics Ltd, 2014).

4.4.6.2.2 Segmentation system and protocol

A modified calibrated anatomical system technique (CAST), which is proposed by Cappozzo et al. (1995), was used to capture lower limb, pelvic and trunk movement patterns. This method involves identifying an anatomical frame for each segment through the identification of anatomical landmarks and segment tracking markers, or marker clusters. Among this, CAST offers the ability to model each body segment in six degrees of freedom, so the interactions and movements between the body segments can then be projected, along with the anatomical axis defined by proximal or distal segments (Richards, 2008).

The modified CAST protocol used in the present project was based on 15 LED markers being attached to the following body landmarks. These markers include acromion, spinal process of seventh cervical and seventh thoracic vertebrae, 10th rib angles, sternal angle, anterior superior iliac spine, posterior superior iliac spine; and four sets of four-marker-clusters being

attached to thighs and shanks as indicated in Figure 2. Three extra LEDs were used to monitor the motion of the ultrasound probe and record its orientation.

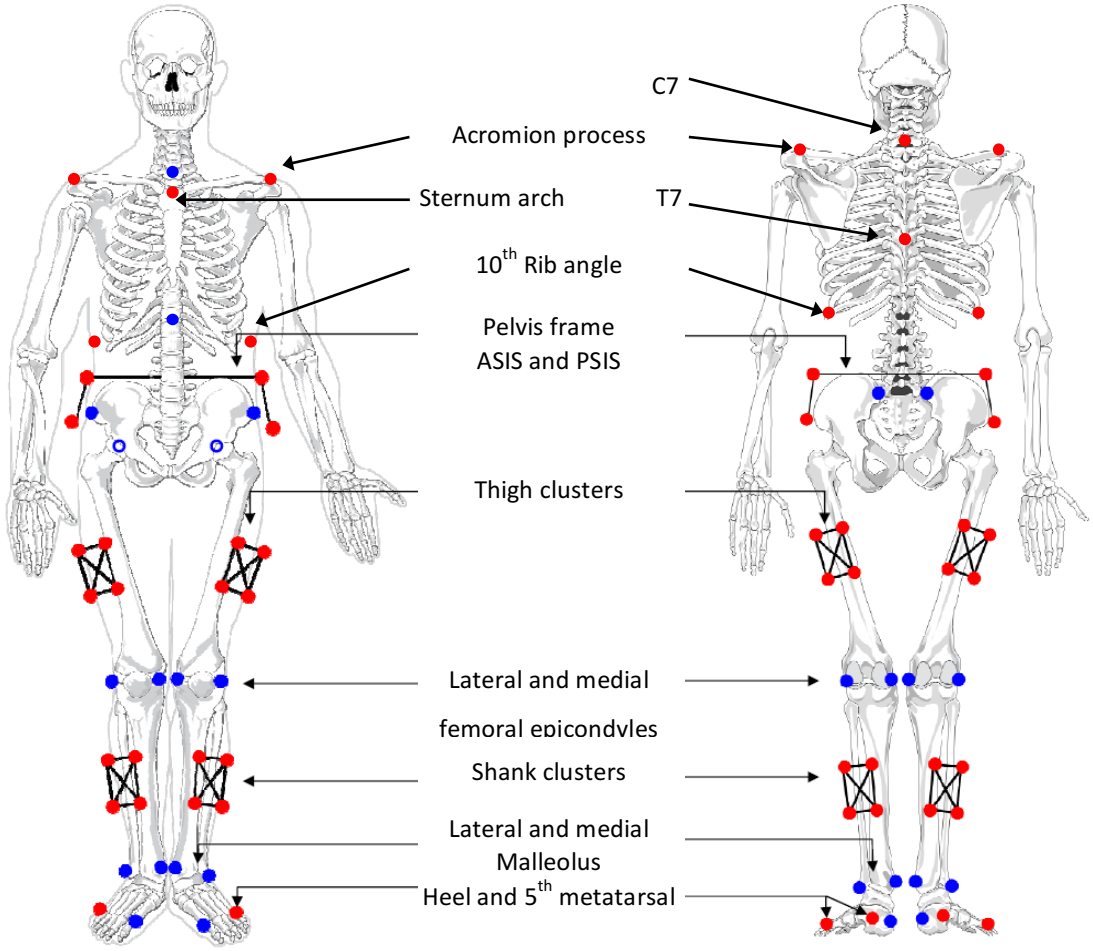


Figure 39. Motion capture marker placements
Red markers: actual active infrared markers.
Blue markers: Computational virtual markers.

The markers were positioned predominantly on bony landmarks and provided data for segmental analysis of lower limb, pelvic and trunk movement. Apart from Codamotion active markers, the virtual markers, which are markers obtained through computations, were also used to build the anatomical frame for segmentation (see Figure 39 for detailed marker lists).

The body was subdivided into seven segments - upper trunk, lower trunk, pelvis, left thigh, right thigh, left shank and right shank, each having a minimum of three associated markers. According to the *Surface-marker cluster design criteria for 3-D bone movement reconstruction* Cappozzo et al. (1997), tracking of these markers within the capture space enables the calculation of individual segmental movements using an embedded vector basis

(EVB) approach which defines a local coordinate system for each segment. For instance, the pelvis coordinate system is as follows: the z-axis was formed by a line joining two anterior superior iliac spines (ASIS), the x-axis formed by the line from middle of two posterior iliac spines (PSIS) to the middle of ASIS perpendicular to the z-axis, and the y-axis perpendicular to the x and z-axes (Figure 40). This was first developed by Bell et al. (1990), validated later on by Leardini et al. (1999), and has been continuously applied subsequently. As per general standards for joint kinematics defined by the Standardisation and Terminology Committee (STC) of the International Society of Biomechanics (ISB), one coordinate basis is attached to each Body segment and the kinematics of each joint is studied through the movement of two relative coordinate systems attached to each adjacent bone of the joint (Wu and Cavanagh, 1995, Wu et al., 2002, Wu et al., 2005).

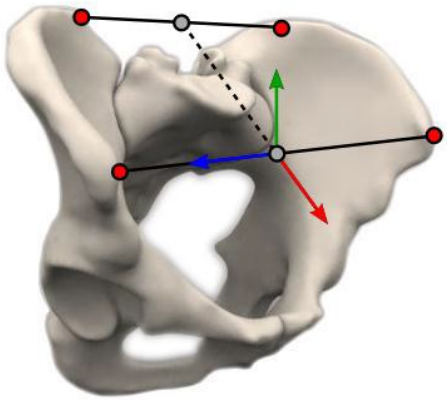


Figure 40. Principle of segment coordinate system (Pelvis)

All body segments involved in this study were calculated following the same principle of segment coordinate system. The descriptions of three or four markers and the construction of each axis of the embedded vector basis of the segments, such as upper trunk (Table 8), lower trunk (Table 9) and lower limbs (Table 11 and Table 12) are detailed below.

Table 8. Details of embedded vector basis of the segments – upper trunk

Upper trunk			
	Markers		**Coordinate Frame**
C7	Spinous process of the 7th cervical vertebra	Origin	The origin coincident with C7
ST	Sternal notch	x-axis	The line connecting C7 and ST
L.AC	Left Shoulder acromion	y-axis	The common line perpendicular to the z and x-axes
R.AC	Right Shoulder acromion	z-axis	The line connecting L.AC and R.AC

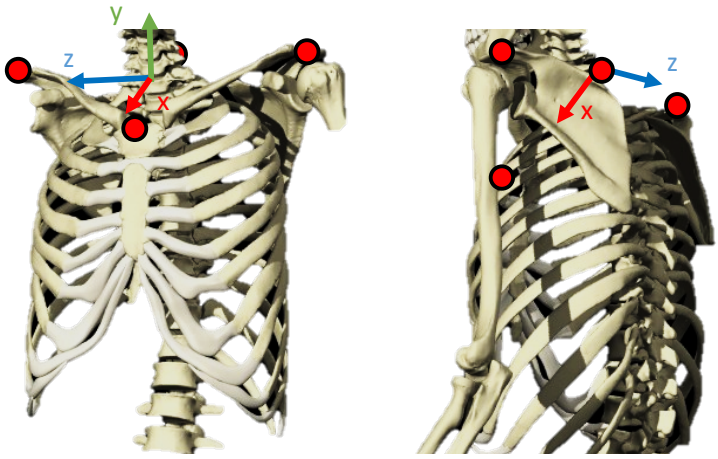


Table 9. Details of embedded vector basis of the segments – lower trunk

Lower trunk			
	Markers		**Coordinate Frame**
C7	Spinous process of the 7th cervical vertebra	Origin	The origin coincident with T7
T7	Spinous process of the 7th Thoracic vertebra	x-axis	The common line perpendicular to the y and z-axes
L.Rib	Left 10th rib angle	y-axis	The line connecting Mid-TR and C7
R.Rib	Right 10th rib angle	z-axis	The line connecting L.Rib and R.Rib
Mid-TR	Mid-point of T7, L.Rib and R.Rib		

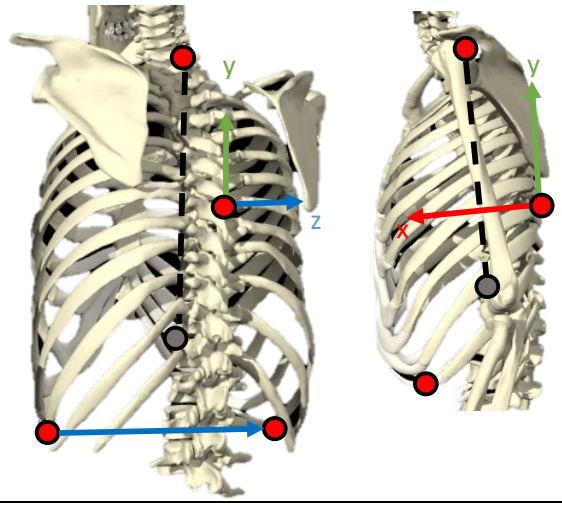


Table 10. Details of embedded vector basis of the segments - pelvis

Pelvis			
	Markers		**Coordinate Frame**
R.ASIS	Right anterior superior iliac spine.	Origin	The origin coincident with MidASIS
L.ASIS	Left anterior superior iliac spine.	x-axis	The line connecting L.ASIS and R.ASIS
R.PSIS	Right posterior superior iliac spine.	y-axis	The line perpendicular to the plane formed by two ASIS and MidPSIS
L.PSIS	Left posterior superior iliac spine.	x-axis	The common line perpendicular to the y and z-axes,
MidASIS	The midpoint between two ASIS		
MidPSIS	The midpoint between two PSIS		

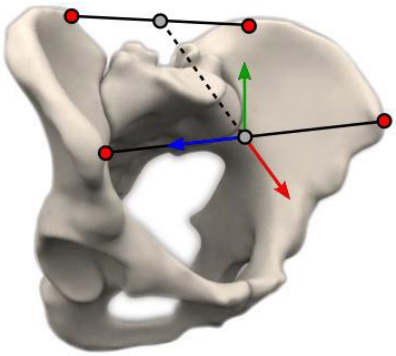


Table 11. Details of embedded vector basis of the segments -thigh

Thigh			
	Markers		**Coordinate Frame**
LFE	Tip of the lateral femoral epicondyle	Origin	The origin coincident with HJC.
MFE	Tip of the medial femoral epicondyle	x-axis	The common line perpendicular to the z and y-axes, pointing anteriorly
IFE	The inter-femoral epicondyle point located midway between R.LFE and R.MFE.	y-axis	The line connecting IFE and HJC, pointing cranially.
HJC	The hip centre of rotation. This point was defined by linear regression.	z-axis	The line perpendicular to the y-axis, lying in the plane defined by HJC, LFE, and MFE, pointing right.

Femoral Coordinate Frame (Cappozzo et al., 1995)

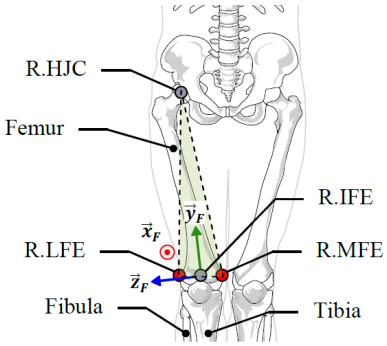
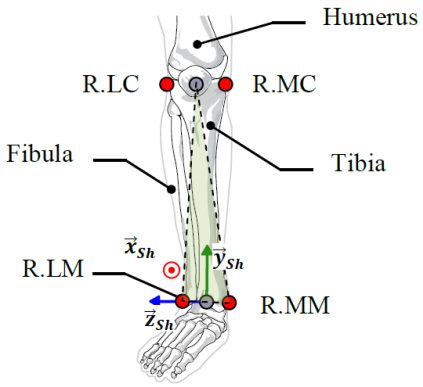


Table 12. Details of embedded vector basis of the segments – calf

Calf			
Markers		**Coordinate Frame**	
MM	Tip of the medial malleolus	Origin	The origin coincident with **IM**.
LM	Tip of the lateral malleolus	x-axis	The line perpendicular to the plane through **IC**, **MM**, and **LM**, pointing anteriorly.
MC	Most caudal point on the border of the medial tibial condyle	y-axis	The common line perpendicular to the z and x-axes.
LC	Most caudal point on the border of the lateral tibial condyle	z-axis	The line connecting **MM** and **LM**, pointing right.
IC	The inter-condylar point located midway between MC and LC.		
IM	The inter-malleolar point located midway between MM and LM.		



4.4.6.2.3 Thoracolumbar flexion movement measurements

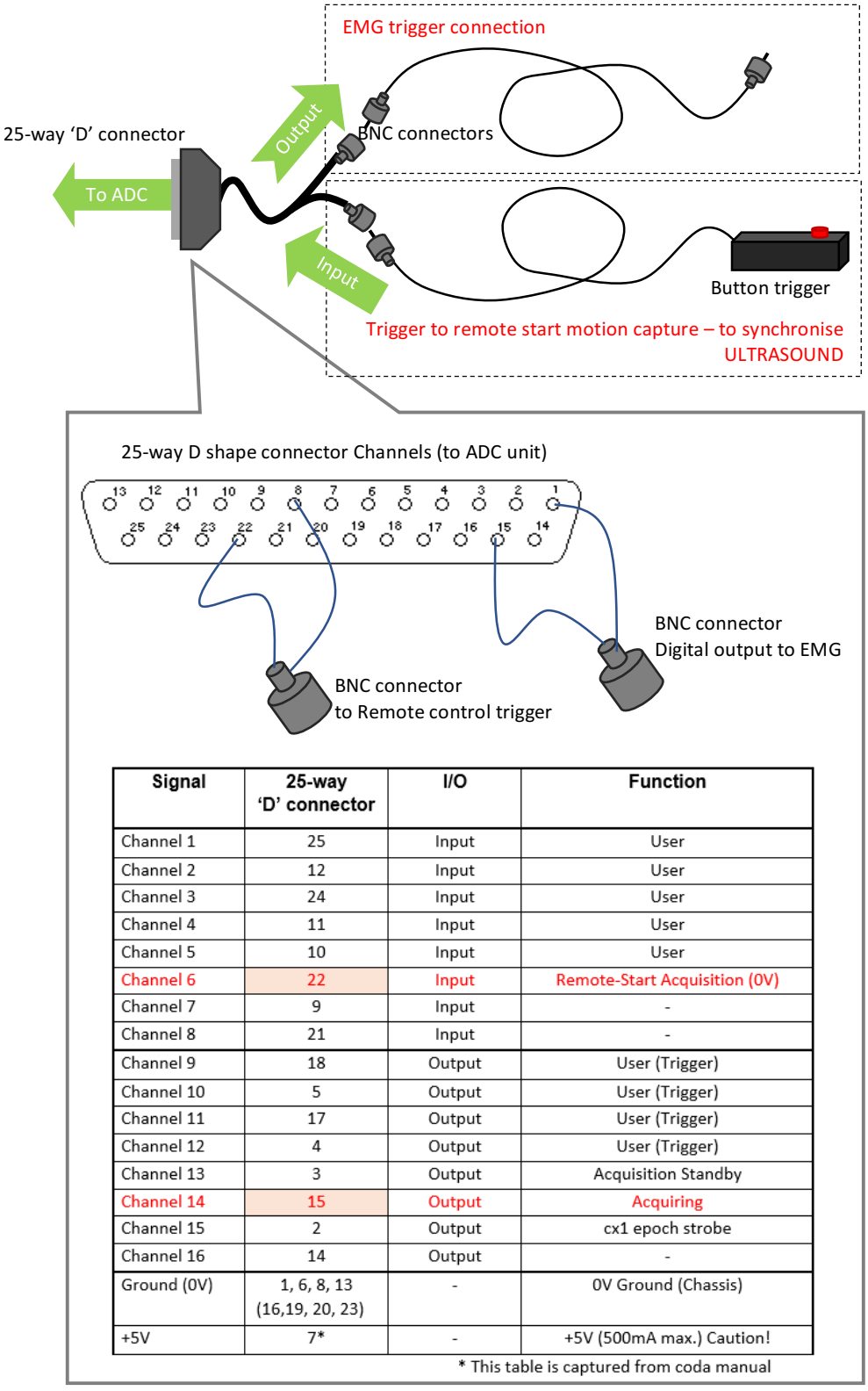
Overall thoracolumbar flexion was defined as the sum of Euler angles of the hip joint, pelvis versus lower trunk and lower trunk versus upper trunk in the sagittal plane. These Euler angles were computed from the distal segment relative to the proximal segment. For example, the hip joint angle used to compute thoracolumbar flexion was a mean value of left and right hip flexion, which were computed from the embedded vector bases of both thigh EVBs to the embedded vector bases of the pelvis EVB. Similarly, the same principle was applied to the relative angles between lower trunk and pelvis and upper trunk and lower trunk.

4.4.7 Synchronisation

Data in the present study were collected using three separate systems. Ultrasound data were collected on a clinical machine which has an independent computer operating system; EMG data were collected using Portilab software, while kinematic data were collected with the CODA motion analysis software on a separate PC. Collecting data synchronously from three independent systems became a major challenge.

Accurate synchronisation between EMG and the kinematic system was ensured through the use of digital signal input and output (I/O) ports on each system. The CODA motion active hub is equipped with an Analogue-to-Digital Converter (ADC) which enables communication with other systems, and the REFA system has one digital signal input port available for external synchronisation. During data collection, the kinematic capturing system was set to send out a 5 V differential Transistor-transistor logic (TTL) signal by the onset and the end of data capture through ADC unit (see Figure 41 – Channel 14). The EMG system received and recorded these signals synchronously with a separate channel. Kinematic and EMG data could then be aligned on the same time axis according to the digital synchronisation signals (Figure 42).

The most challenge part of synchronisation was the Ultrasound due to lack of robust input/output ability. This was achieved by using the 'remote start' function on the CODA motion hub through a microswitch. A microswitch was connected to channel six on the ADC unit (see Figure 41), and the kinematic software was set to start capturing data on the reception of the trigger signal. While collecting data, the trigger was pulled at the same time with start capturing trigger on the ultrasound machine. Pulling two triggers at the same time was a particular challenge of the whole synchronisation procedure. However, the design of a second version of the microswitch trigger provided a better synchronisation result. As shown in Figure 43, instead of triggering with two fingers at the same time, two triggers were physically contacted and can be activated by a single action, which significantly reduced the human error. Outcomes of a later synchronisation test confirmed this improvement. The complete hardware connection design is shown in Figure 44, and a flowchart is given to describe the synchronisation procedure (Figure 45).



Signal	25-way 'D' connector	I/O	Function
Channel 1	25	Input	User
Channel 2	12	Input	User
Channel 3	24	Input	User
Channel 4	11	Input	User
Channel 5	10	Input	User
Channel 6	22	Input	Remote-Start Acquisition (0V)
Channel 7	9	Input	-
Channel 8	21	Input	-
Channel 9	18	Output	User (Trigger)
Channel 10	5	Output	User (Trigger)
Channel 11	17	Output	User (Trigger)
Channel 12	4	Output	User (Trigger)
Channel 13	3	Output	Acquisition Standby
Channel 14	15	Output	Acquiring
Channel 15	2	Output	cx1 epoch strobe
Channel 16	14	Output	-
Ground (0V)	1, 6, 8, 13 (16,19, 20, 23)	-	0V Ground (Chassis)
+5V	7*	-	+5V (500mA max.) Caution!

* This table is captured from coda manual

Figure 41. Synchronisation adopter unit design and CODA I/O connection index
Top: I/O connection adopter and cable design
Bottom: Channel index for 25-way D connector on Coda Motion Active Hub I/O unit

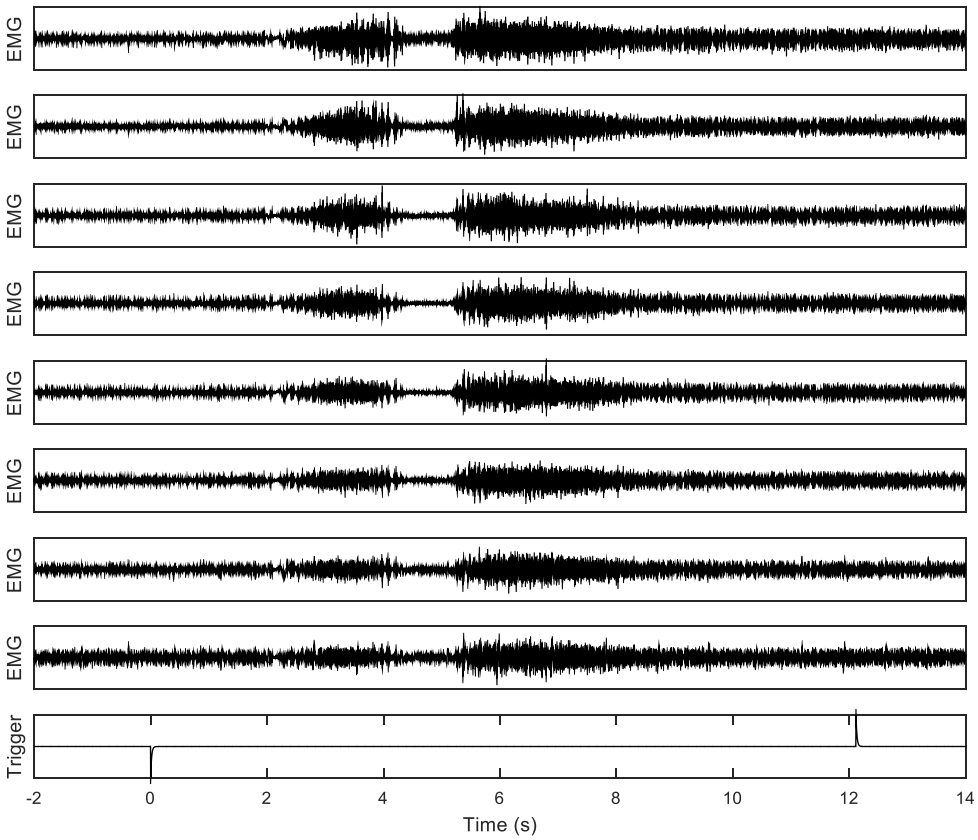


Figure 42. Example of EMG signals and digital synchronisation signals

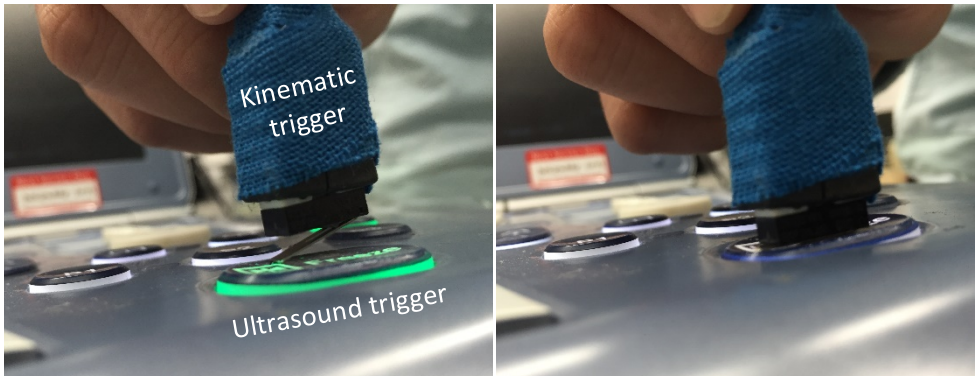


Figure 43. Improved version of microswitch trigger for synchronisation of ultrasound and kinematics
Left: trigger not activated; Right: trigger activated

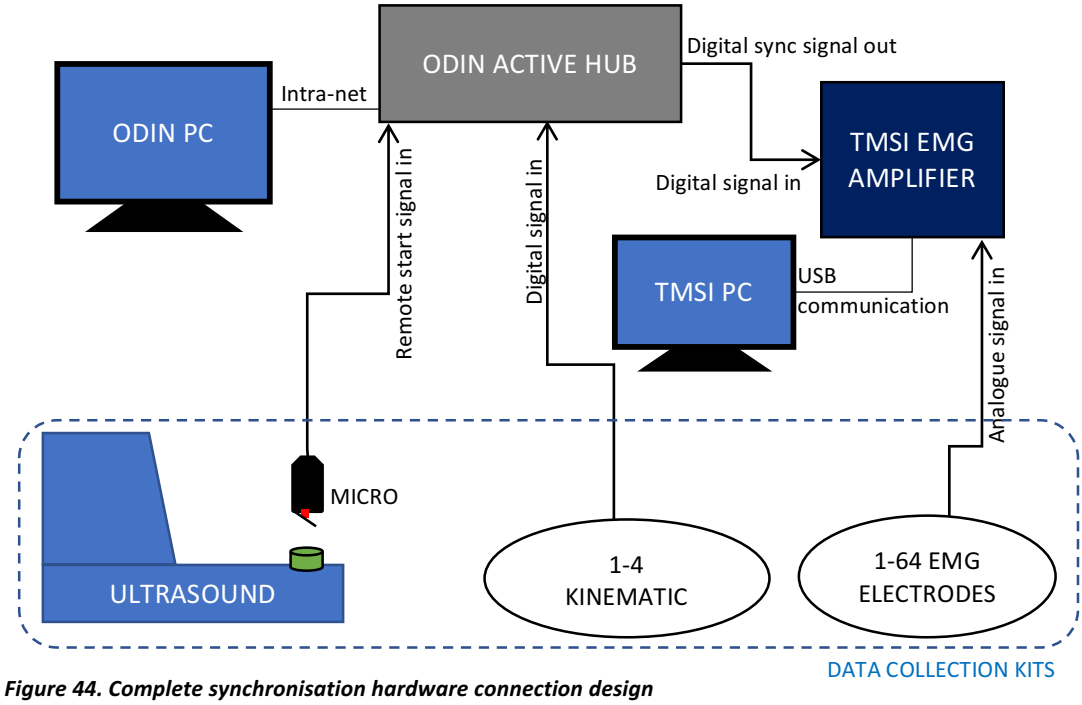


Figure 44. Complete synchronisation hardware connection design

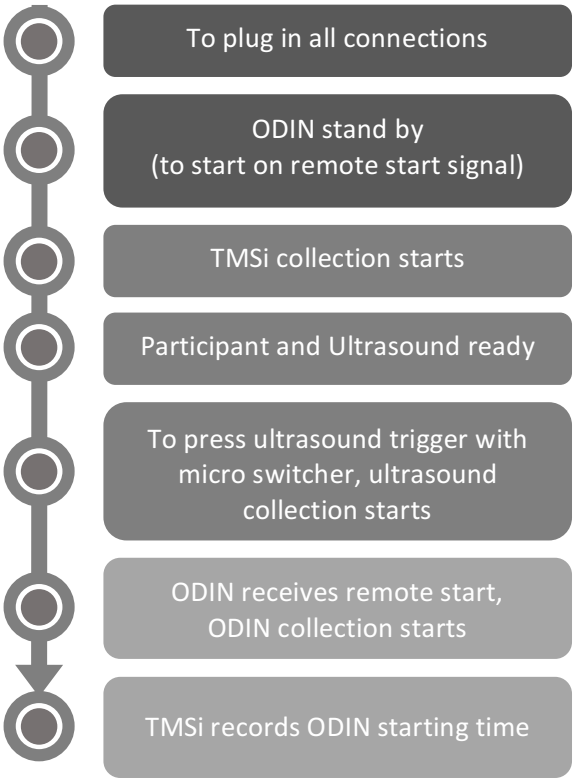


Figure 45. Flowchart of Synchronisation process

4.4.7.1 Monitoring Synchronisation delays and error

Due to the limited number of I/O ports, three systems involved in the present project were not directly synchronised by a single signal handler. The motion capture system – Odin, which has more ports available for synchronisation, played the bridging role between the EMG system and the Ultrasound machine. In fact, the synchronisation in this project was achieved by pairing Odin to TMSi and the ultrasound machine at the same time. Therefore, this section aims to demonstrate the process of synchronisation quality check between Odin and TMSi as well as Odin and the ultrasound machine.

4.4.7.1.1 Synchronisation between ODIN and TMSi

Examining synchronisation between Odin and TMSi system was a less challenging task. TMSi is a multichannel signal handler, and it was directly connected to Odin via an *analogue to the digital* signal converter. The synchronisation check was performed by recording the same simple muscle activity via two systems. A set of EMG system (Trigno, Delsys ®, Inc., Natick, MA) was connected to the analogue port of ODIN hub; this was therefore used as a reference to compare with the signal recorded on TMSi system. As shown in Figure 46, two sets of electrodes were attached to a similar position on the same arm. A serious of metronome guided tapping movements was performed to check if peak activation signals received from two systems can be aligned. An example of signal alignment is also shown in Figure 46. The same procedure has been performed a few times, and thirty-six contractions were collected to examine the accuracy of signal timing. The reference EMG signals were processed using the procedure described in section 4.4.5.5.2 before checking time shifts. Signals from two EMG system were compared and the time shift between two systems was 0.024 ± 0.064 seconds. Therefore, to be aligned with ODIN data, TMSi data were shifted 48 samples (0.024*sampling frequency) in the data processing before variable extractions.

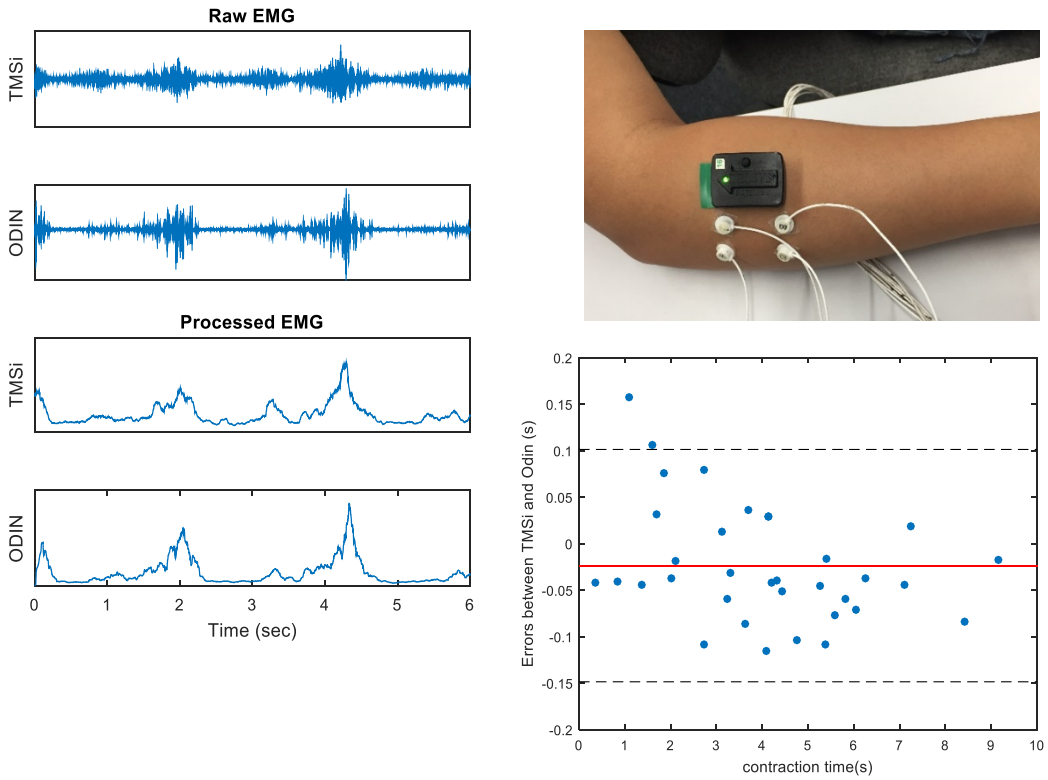


Figure 46. Settings of EMG synchronisation test

Left: *EMG signals recorded from two systems for the synchronisation check. Although the shapes of envelopes of EMG were not identical due to the electrode placement, the peak activation time can still be used to check if there is any delay between two systems.*

Top right: *two sets of electrodes were attached to a similar position on the same arm to record the same muscle activation pulse to examine the synchronisation between two systems.*

Bottom right: *Blend and Altman plot for the comparison of contraction times recorded from two systems.*

4.4.7.1.2 Synchronisation between ODIN and Ultrasound

As shown in the synchronisation flowchart Figure 47, Odin was set to wait for an external trigger before starting acquisition during the actual experiment. As soon as the external trigger was pulled at the same time with the ultrasound acquisition, Odin sent out a signal and started acquiring data at the same moment. A multifunction I/O device (USB-6210, National Instruments) was used to record the external signal and Odin synchronisation output as an independent monitoring platform to examine delays and errors of synchronisation between Odin and the ultrasound system. The external trigger signal and the Odin trigger output were real-time recorded. Thirteen sets of data were collected for this purpose. Correlation between the starting time of each system was assessed using Pearson correlation, limits of agreement (LOAs) were calculated for each assessment and systematic differences tested with a Student's t-test.

As shown in Figure 48 a significant delay of 0.89s ± 0.013 was detected ($t = 239.66$, $df = 12$, $p < 0.001$). All data of time shifting was listed in Table 13. Despite the significance, the starting time of two system was highly related ($r = 0.999$), this result shows the delays were consistent. Limit of agreement analysis (Figure 49) shows the result was accepted and the resolution of this synchronisation triggering system was 0.053 seconds. Although potential error up to 0.053 seconds may occur, only slow movements were involved in the experiments of this PhD, so this resolution was deemed acceptable.

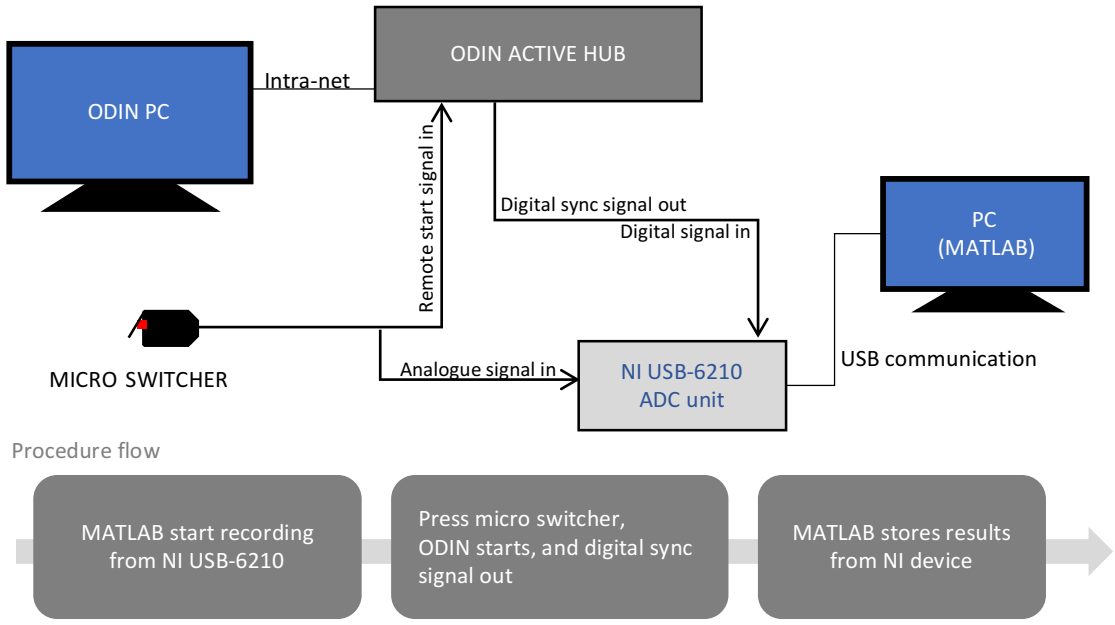


Figure 47. Hardware settings and flowchart for ODIN-ultrasound syncronisation tests

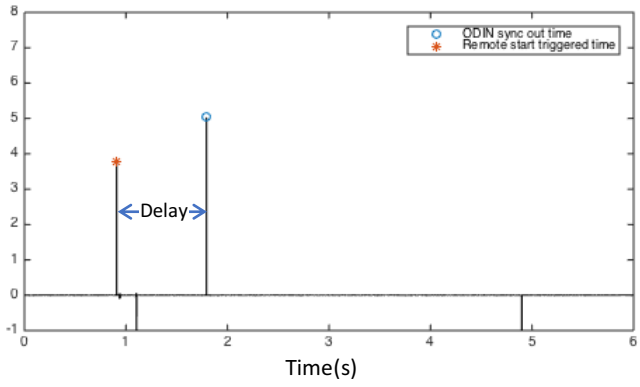


Figure 48. An Example plot for the result of synchronisation testing (one of 13 tests)

**: signal received from the external remote start micro switcher*

o: ODIN synchronisation signal output when it starts data acquisition

Table 13. Results of monitoring synchronisation between two trigger signals

Trial no.	External trigger time	ODIN starting time	Time difference	Mean difference	SD	ICC
1	2.623	3.512	0.889			
2	1.516	2.434	0.918			
3	1.259	2.145	0.886			
4	1.567	2.467	0.900			
5	1.803	2.682	0.879			
6	1.803	2.682	0.879			
7	0.801	1.705	0.904	0.890	0.013	0.999
8	1.130	2.029	0.899			
9	0.849	1.753	0.904			
10	0.883	1.762	0.879			
11	0.979	1.855	0.876			
12	0.863	1.739	0.876			
13	0.909	1.794	0.885			

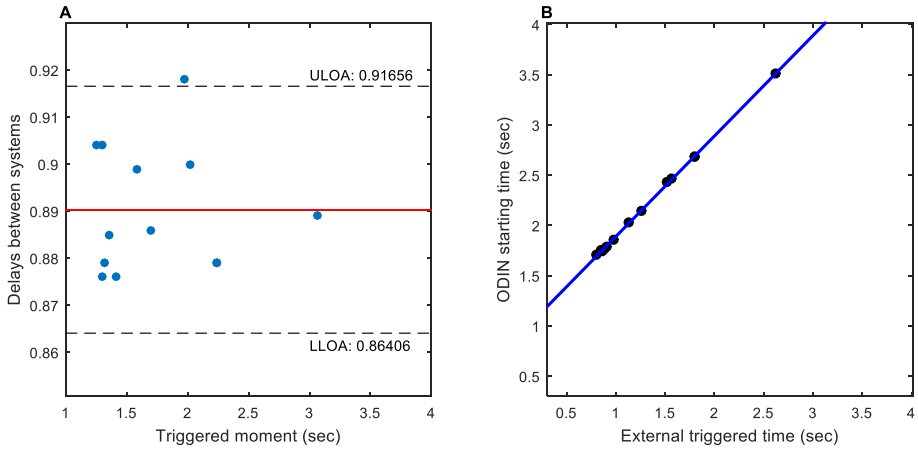


Figure 49. Blend and Altman and x-y plot for the result of triggering test

A: *Blend and Altman plot for the trigger delays assessment*

B: *correlation between triggering time and actual starting time. (ICC= 0.99, delay = 0.89 s)*

Even though the external trigger can be aligned with Odin data after the shifting offset was measured and adjusted, the consistency of ultrasound recording onset can still be misaligned. This misalignment has also been examined in the monitoring test. To achieve this test, an event which was detectable by both kinematic system (Odin) and an ultrasound system was designed. A table with the flat, smooth surface was prepared for this test. A cluster of motion markers was placed on the surface to record the surface position for later calculation. An ultrasound probe transducers with gel were lifted to approximately 70 centimetres above the surface of the table (Figure 50A). The event for checking synchronisation was to put down the transducer and touch the surface. The ultrasound image immediately changed from bright to dark due to reflection from the table (Figure 50B). Another cluster of motion markers was used to record positions of the ultrasound transducer probe.

Before comparing two sets of data, the cine ultrasound images were converted to correlation values between every two adjacent frames which enables to detect the moment when the probe contacts the surface (Figure 50D). On the other hand, the probe contact moments were detected by comparing the distance between the probe and the surface in motion capturing data (Figure 50E). As shown in Figure 50C, the delay between Odin receiving the remote start trigger and an actual start has been adjusted according to the results provided in Table 13. Two starting trigger and data sets were ideally aligned.

A consistent shifting offset was detected, and the results were listed in Table 14. Mean shift time between two systems was 0.713 ± 0.051 second. Therefore, all collected data need to be shifted according to this result before being processed variable extraction, and the potential error is up to 0.20 second.

4.4.7.1.3 Outcome of synchronisation monitoring

Despite the complexity, an acceptable synchronisation between the three systems - kinematic, EMG and ultrasound has been achieved by iterative loop trigger design and monitoring tests. Delays and shifts between machines were consistent and can be adjusted after data collection. Trigger signals have been recorded to align all three types of signals. Due to the input/output functionality limitations of the ultrasound machine, this synchronisation design cannot guarantee a perfect signal alignment. However, the current solution was carefully examined in multiple series of tests, which promised an optimal synchronising result for the further experiments in this project. In summary, the synchronisation development and results of accuracy check were deemed as being acceptable.

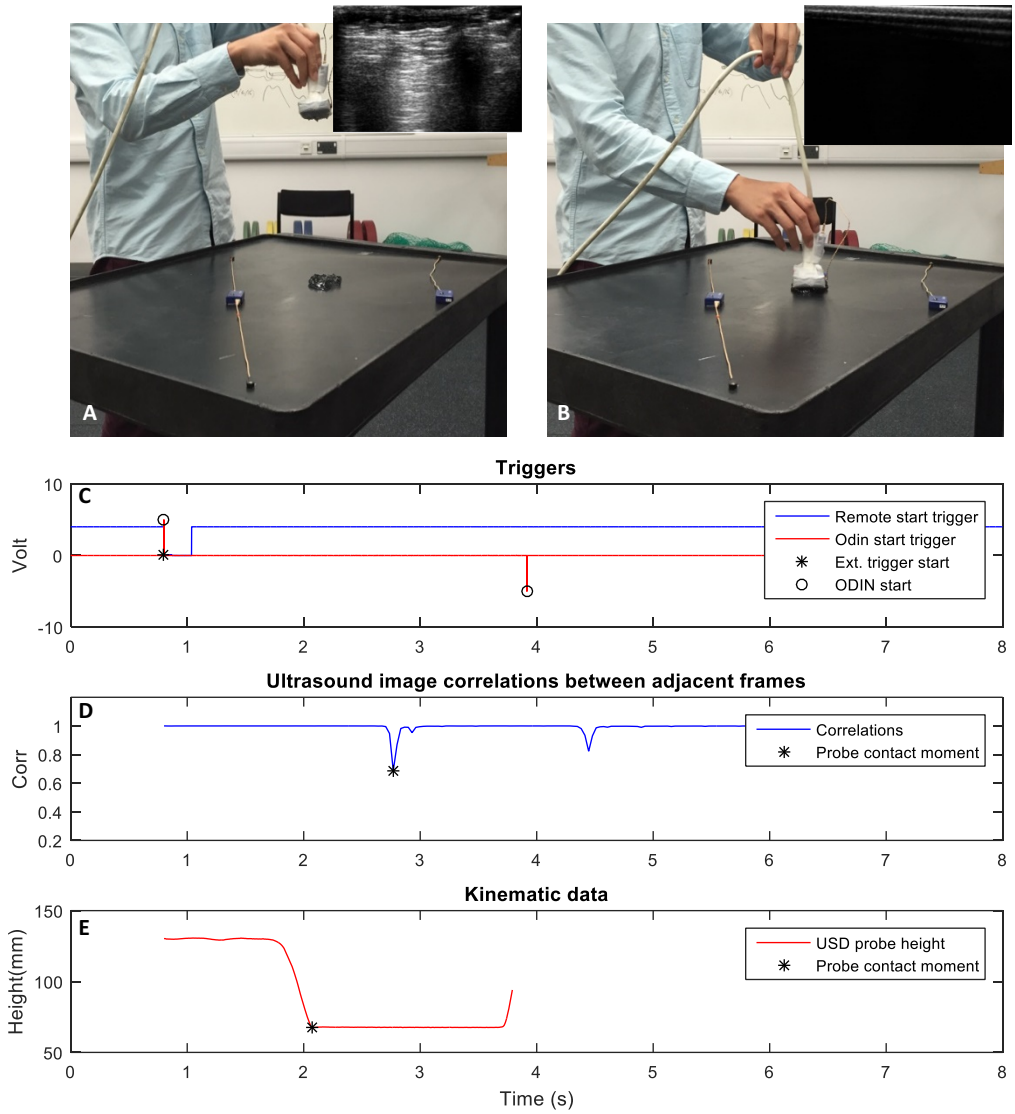


Figure 50. Device setting and demonstration outcome in ultrasound acquisition delay testing

A: Initial position of the ultrasound probe. The image displays echo from the gel.

B: The ultrasound probe contacted table surface. The image displays no deeper echo.

C: Triggers from kinematic capture system and ultrasound starting trigger (remote start for kinematic system), delay between two system has been adjusted as per result of Table 13

D: Correlations between adjacent ultrasound image frames. The correlation dips reveal changing status (from no contact to contacted, and from contacted to no contact)

E: Distance between ultrasound probe tail and table surface. This data enables detection of contact time.

Table 14. Results of monitoring synchronisation between ODIN and Ultrasound

Trial no.	Contact time in Ultrasound	Contact time in ODIN	Time difference	Mean difference	SD	Person r
1	2.769	2.071	0.698			
2	2.130	1.440	0.690			
3	1.996	1.269	0.727			
4	2.124	1.513	0.611			
5	2.626	1.939	0.687			
6	2.363	1.723	0.640			
7	2.585	1.919	0.666			
8	3.086	2.321	0.765			
9	1.986	1.331	0.655			
10	2.211	1.500	0.711	0.713	0.051	0.986
11	2.206	1.466	0.740			
12	2.322	1.544	0.778			
13	2.117	1.395	0.722			
14	2.202	1.408	0.794			
15	1.993	1.289	0.704			
16	2.152	1.441	0.711			
17	2.121	1.338	0.783			
18	1.858	1.130	0.728			
19	2.081	1.418	0.663			
20	2.068	1.284	0.784			

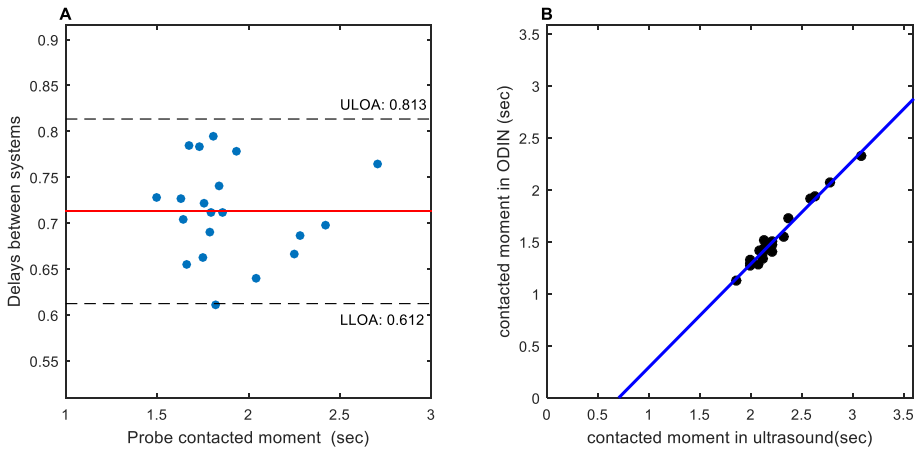


Figure 51. Blend and Altman, and x-y, plots for the results of synchronisation test between ultrasound and kinematic system

A: *Blend and Altman plot for the cross-system delays assessment*

B: *correlation between time measurements across two systems. (ICC= 0.99, delay = 0.70s)*

4.5 Data analysis

4.5.1 Nature of data sets

A large amount of data sets were collected in this project. These data were ultrasound videos, multi-channel EMG signals, and kinematic marker positions. These datasets were all converted to numeric complexes for processing, and therefore have unique structure after processing. It is necessary to choose carefully to extract relevant and useful information and filter out those irrelevant noises.

Kinematics contains eight relative joint movements in a three-dimension coordinate, and seven local coordinates (trunk and lower limb were divided into seven segments). All segmentation data are time series so that it can be considered as seven sets of the 4-dimensional data sheet. EMG data has the simplest structure in this study; they are sixteen sets of time series (2-dimension). Processed ultrasound movement map can be considered as a number of time-series of two-dimensional movements.

4.5.2 Confounding variables extraction

4.5.2.1 Ultrasound variables – tissue properties and characteristics

The designated movement tasks were divided into phases according to the kinematic datasets of upper, lower trunk and pelvis rotation in the sagittal plane. Flexion and extension phases were defined according to these curves by detecting the moment when the participants started the movement and reached their maximum flexion. Figure 52 gives an example of kinematic data in the sagittal plane in contrast with stick figures and result of phase detection. The timing of the onset and the end of flexion and extension phase were then converted to frame numbers according to the sampling rate of kinematic data and the frame rate of the ultrasound clip.

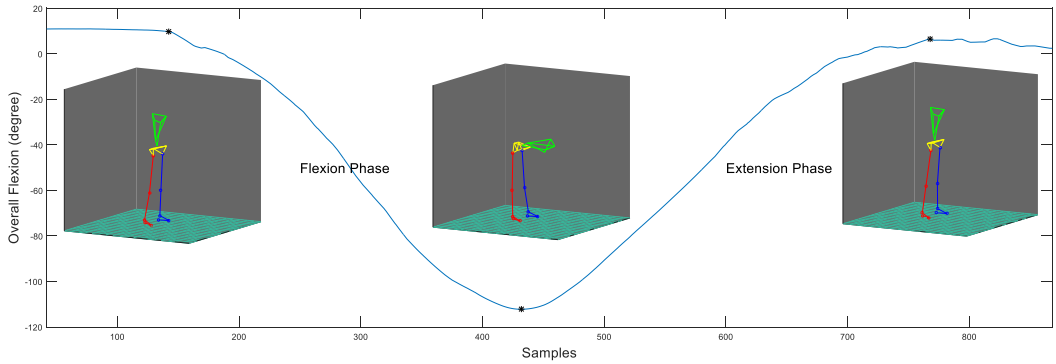


Figure 52. Example of flexion / extension phase detection

Once the frame numbers were retrieved, the ultrasound clip was chunked into two clips according to these indexes, ready for the next analysis stage. These chunked video clips were processed with the procedure as described in section 4.4.1.5.1.3. Boundaries between four tissue zones, including skin, subcutaneous, peri-muscular and muscular zones, were visually defined before ROI feature tracking. A tissue movement map were plotted and saved after this procedure (Figure 20). Further outcome variables, including layer movement, para-cutaneous translation and layer deformation, were then calculated according to this tissue movement map.

4.5.2.1.1 Layer movements

Layer movements were calculated by comparing positions of a specific target feature in two directions at two different moments. Caudal to rostral movements and anterior to posterior movements were counted separately initially as the direction of the tissue movement can be considered in this approach of comparisons. Caudal rostral movements are regarded as

$$\boldsymbol{CR_{movs}} = \sum_{i=1}^{n-1} \boldsymbol{Pos_{c,i+1} - Pos_{c,i}}$$

(Equation 1)

Where *n* is a total number of frames and *c* is column index of the positions. Similarly, the amount of anterior-posterior is calculated as

$$\boldsymbol{AP_{movs}} = \sum_{i=1}^{n-1} \boldsymbol{Pos_{r,i+1} - Pos_{r,i}}$$

(Equation 2)

Overall route movements which contain both directions were then calculated to detect small changes are regarded as

$$\boldsymbol{Overall_{movs}} = \sum_{i=1}^{n-1} \sqrt{\left(\boldsymbol{POS_{c,i+1} - POS_{c,i}}\right)^2 + \left(\boldsymbol{POS_{r,i+1} - POS_{r,i}}\right)^2}$$

(Equation 3)

Figure 53 is an example revealing relations and differences between these variables. It shows that simply considering movements in one axis, Caudal-rostral movements for example, missed information of initial direction change and underestimated the amount of movement, but revealed a major movement direction. While the overall route length included all movement amounts, it ignored movement directions.

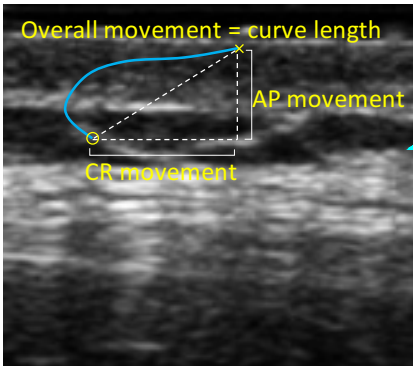


Figure 53. An example of three variable extractions.
o: starting position;
x: end position of tracked ROI

4.5.2.1.2 Para-cutaneous tissue translation

'Para-cutaneous tissue translation' is a term used to describe the relative movements of two layers on either side of a tissue boundary, approximately parallel to the skin surface. A few examples of this calculation are given in Figure 54.

This term was firstly used in the published paper which contributed to *Chapter 5.1* of the present thesis (Tu et al. 2016). Several terms considered by the investigator before this publication were, still, not clear. For example, 'Shear strain', the ratio of deformation to original dimensions, was commonly used in previous studies because shape changes of the thoracolumbar fascial images were analysed and discussed (Langevin et al., 2011). However, the thoracolumbar tissue movements were monitored, and the difference between two sides of tissue boundaries was computed in the present study and do not accurately fit the definition of shear strain. Apart from this, 'Gliding', which is a common term to describe movement at joint surfaces, was also considered. Although boundaries on the sub-cutaneous lumbar tissue can be seen, and the movement appearance was very similar gliding. However, the boundaries between skin, fascia and muscles are not as clear an interface as joint surfaces. Connective tissues are connecting one layer to another regardless of their movement direction, and there are movement translations through layers. Therefore, 'para-cutaneous tissue translation' was used to describe the observed phenomenon.

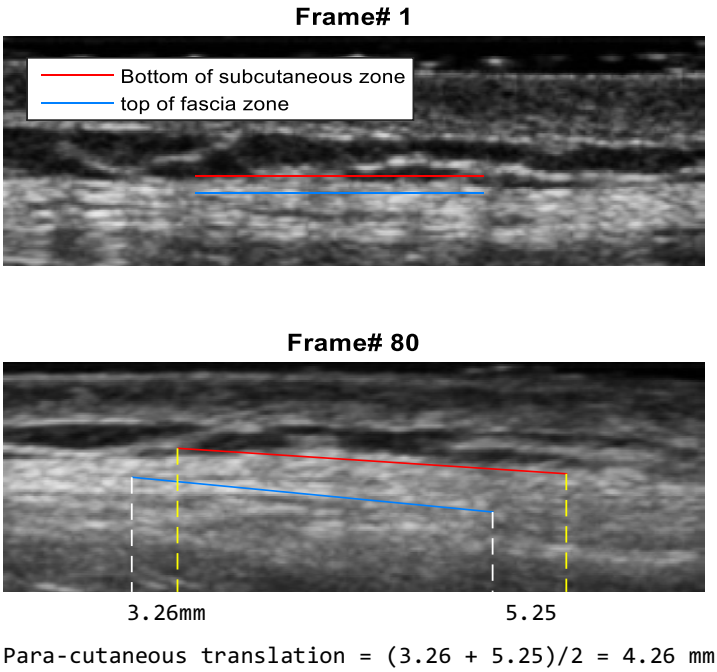


Figure 54. Examples of extracting Para-cutaneous tissue translation.

This example shows how para-cutaneous tissue translation in the boundary between the subcutaneous zone (red line) and the fascia zone (blue line). Translations were defined as a mean movement differences between two layers across the layer boundary.

4.5.2.1.3 Layer deformations

Layer deformations were defined as changes in the shape of tissue layers. The target position grid described in section 4.4.1.5.1.3 was the key information to compute this variable. The area of initial grid point was recorded, and the deformed grid was recorded according to the new positions of tissue according to the automatic tracking. Moreover, finally, the difference between initial grid and the deformed grid was computed and extracted as a variable for statistical comparison.

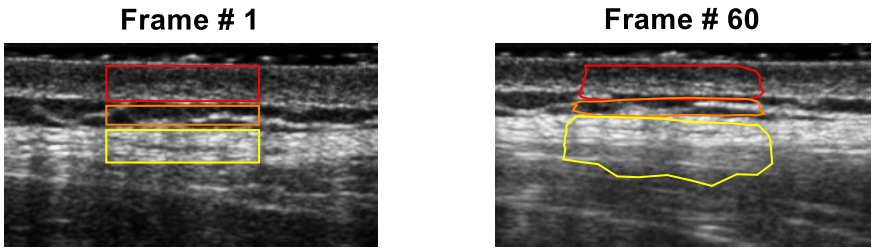


Figure 55. Examples of layer deformations.

Layer areas were drawn according to the tracking grids, and Layer deformations were the area changes in following layers
Red area: skin
Orange area: subcutaneous zone (superficial fascia)
Yellow area: fascia zone

4.5.2.2 EMG variables

The main aim of extracting EMG variables was to investigate muscle activation differences during the experimental task before and after KT was applied. This section contains some selected EMG variables and how they were extracted. The purpose of including EMG analysis was to discover if muscle activation could explain the tissue movement changes observed during the experimental movement tasks. This would help to clarify the source of the mechanism for observed changes in the clinical measurement.

4.5.2.2.1 Mean amplitude

The filtered, rectified and smoothed (enveloped) EMG signal was extracted for the duration of the flexion and extension phases during the experimental task, using the kinematic data as described above. The mean values of each channel were taken from two phases to compare the difference between the condition of with and without KT.

4.5.2.2.2 Integral of EMG

Although the experimental task was a speed guided movement, the duration and the range of movement varied between participants, the RMS EMG data was posture normalised by interpolating all data to the number of samples in the longest duration sample. This enabled calculation of integral EMG values without confounding influence from contraction duration. Integral EMG calculations were performed on posture-registered EMG data using the trapezoidal method to calculate the area under the curve of the signal for each channel. The area under the curve of the RMS signal provides a representation of the overall volume of the muscle activity (Konrad, 2006, Richards, 2008). The decision to normalise the RMS signal in this way is somewhat unconventional, but controlling the duration of the experimental task was difficult. Therefore, it was necessary to normalise according to movement duration/posture. Resampling to the duration as percentage eliminated the risk of data loss using the alternative of shortening.

4.5.2.2.3 Activation vs time/posture

One of the important aims of EMG analyses was to confirm if EMG differs from each condition which is parallel to the findings of ultrasound analyses. Simply extracting mean amplitude or integral EMG from each phase, may lose key information, because KT may affect the soft-tissue and muscle activity at the whole duration of the task movement rather than a specific moment.

4.5.2.2.4 Median power frequency

The median frequency for the EMG signal of each channel was calculated. The frequency spectrum provides information about the underlying nature of the motor units contributing to overall signals with larger fast twitch motor units thought to fire at higher frequencies. The filtered, rectified signal was extracted for the duration of the flexion and extension phases, using the kinematic data as described above. A Fourier transform was performed across the entire signal to extract the power frequency components spectrum. The median frequency was subsequently calculated according to the power spectrum for each channel.

4.5.2.3 Kinematics variables

Apart from being an index for Ultrasonic and EMG data analysis, kinematic data can itself be useful to detect taping mechanisms. Details of extracted features are given in this section.

4.5.2.3.1 Maximum lumbar flexion positions

Maximum lumbar flexion position is a term used to describe the posture of the end of flexion when the participants were performing the experimental movement tasks. It was a sum of measures of following angles in sagittal plane: mean of hip angles, the angle of lower trunk and pelvis and angle of upper trunk and lower trunk. As described in Figure 52 when defining movement phases. Maximum lumbar flexion position was taken from the sample which had the largest overall flexion angle.

4.5.2.3.2 Range of overall lumbar motion

Clinical assessment of the range of motion in LBP patients often involves measurements in one or two dimensions. However, the lumbar spine is a complex structure involving a number of motion segments and intervertebral joints. Hence it can be expected to exhibit complex three-dimensional (3D) movements. The range of motion in this study was extracted by comparing the sum of angle measures, mentioned in above section, at the beginning and end of the experimental movement task. The same method can also apply to the coronal and frontal plane, but the present project was focussed on the sagittal plane.

4.5.3 Statistical analysis

Statistical analysis was performed using SPSS (IBM SPSS Statistics, version 22.0) and MATLAB Statistical toolbox (R2015a, Mathwork; MA, USA). Descriptive statistics were used to characterize the study sample. Data normality was checked by using the Shapiro-Wilk test to ensure all data are relevant for the further statistical test. Statistical analyses were conducted at a 95% confidence level. P value < 0.05 was considered significant.

To examine the effects of KT on asymptomatic participants (Chapter 5.1), paired T-test was used for the inter-group analysis in normally distributed data sets, and the Wilcoxon's signed rank test was used for the analysis if any sets of variables were to be found non-normally distributed.

Two-way repeated measured ANOVAs were used to compare main factors of taping, posture and Interactions in Chapter 5.2. Because multiple variables were extracted from the same ultrasound video processing procedures, these variables were considered correlated. Therefore, two–way Multivariate analyses of variance (MANOVA) with repeated measures were used to detect changes in tissue movements at four zones and para-cutaneous translations at three boundaries before and after KT was applied (Chapter 6).

Apart from confounding variables, VAS scores during the experimental tasks were recorded as an index to define responders/non-responders' subgroups from the symptomatic participants. MANOVA was used to examine if the linear combination of all variables were different between subgroups

4.6 Chapter summary

This chapter was presented as an account of the early part of my PhD journey. Starting from trying to solve a single research question, a serious of methodological developments were performed and recorded in the sections of this chapter, including innovation of ultrasound-based soft tissue measurement techniques, which is the most important measurement approach in my PhD; design of experimental protocol and selection of biomechanical parameters, such as joint kinematics and EMG; design of synchronisation unit and its quality check, and finally, the selection of statistical analysis methods. No single part of the methodology of this PhD project was fully developed before my study. A combination of struggles, adjustments, customised design and scientific testing is the best descriptions of this experimental procedure development. However, summarising this chapter means all methods have been developed and improved. These are inevitably far from perfect, but accurate enough to produce reliable measurement variables. Apart from being a technical descriptions document, I believe this chapter can also serve as useful educational material for biomechanical laboratory users.

CHAPTER 5 EXPLORING MECHANISMS AND EFFECTS OF KINESIO-TAPING

This chapter contains two independent observational projects involving asymptomatic participants to explore two key elements of KT mechanisms. The first project measured tissue dynamics, including deformation and para-cutaneous translation between tissue layers, alongside kinematic data as the reference of complete trunk movement, and electromyography data to examaine if influences of KT on the soft tissue were explained by muscle activation patterns. The second project was focussed on the examination of tissue stiffness changes on the thoracolumbar fascia using ultrasound elastography before and after KT and sham taping. The work described in this section was designed to obtain a better understanding of the impact of KT on tissue dynamics. Even though these in-vivo works cannot yet provide a concrete conclusion about KT's mechanisms, these studies helped to refine approaches to this topic before measuring symptomatic volunteers.

5.1 Observational laboratory study I – Tissue movement

Can KT alter thoracolumbar fascia movement during lumbar flexion?

Part of data in this section was published as a research paper in the *Journal of Bodywork and Movement Therapy*, Volume 20, Issue 4, Page 898-905.

5.1.1 Background

Despite a poor understanding of KT's actual effects and mechanisms of action, widespread use of the technique has become an interesting and relatively new modality in treating musculoskeletal conditions, including rotator cuff tendonitis (Thelen et al., 2008), shoulder impingement syndrome (Kaya et al., 2011), acute whiplash (Gonzalez-Iglesias et al., 2009), patellofemoral pain (Akbas et al., 2011), and chronic LBP (Castro-Sánchez et al., 2012, Paoloni et al., 2011). This popularity may be due to the structure of the tape, which can be stretched along the longitudinal axis yet allows free movement of the taped body area. Other features of KT, such as its being thin, latex free and anti-allergenic or able to feature fashionable colours and patterns, may also be a marketing strength which has augmented the propensity to use KT. A frequent use is in flexion related LBP (AlBahel et al., 2013, Paoloni et al., 2011).

LBP is a common disorder with a high recurrence and lifetime prevalence (Hoy et al., 2010). The condition represents a considerable socioeconomic burden to the healthcare system and society more generally due to the costs of treatment and time lost from work (Manchikanti et al., 2009, Martin et al., 2008). The cause of back pain remains unclear in over 80% of cases, even though some common spinal disorders related to LBP have been defined (Videman and Battié, 2012). Although current clinical practice guidelines recommend several treatments for LBP, most randomised controlled trials have shown that these treatments provide only mild to moderate clinical improvement in LBP patients (Van Tulder et al., 2006). The same guidelines also state that no difference has been proved between the various modalities of exercise-based therapy as well as manual therapy techniques. We, therefore, need better treatments. KT has been evaluated as a possible adjunct treatment. By adjunct, I mean a facilitator of treatments with longer-term effect.

A particular problem in understanding the role of KT in LBP treatment is that there are many ways of applying KT, with different suggested underlying mechanisms yet the literature has focussed on effects possibly to the detriment of our understanding and application. Five systematic reviews (Kalron and Bar-Sela, 2013, Morris et al., 2013, Mostafavifar et al., 2012, Parreira et al., 2014a, Williams et al., 2012) examining the clinical effects of KT application in musculoskeletal and sports-related injuries concluded that KT may only have a small beneficial effect. However, the reports are somewhat confused by the diversity of taping approaches combined in evidence synthesis. All reviews are discussing similar materials that include some low-quality trials or small sample sizes. The most recent review (Parreira et al., 2014a) even directly concluded that current evidence does not support the clinical importance of KT, because the benefit effect founded it the current studies were either too small to be clinically worthwhile or not significant. To summarise, current evidence may not be enough to support the efficacy of KT application. However, judging effects without clarity about the underlying mechanism of KT may confound clinical studies. A few of these have evaluated this therapeutic tool and were either looking at different conditions or investigating with a diversity of approaches. To date, there is no robust evidence to link pathophysiological effects and actual body reactions triggered by KT. Thus no clear direction has emerged to suggest these considerations translate into clinical practice.

Due to a poor understanding of the mechanism of chronic non-specific LBP, treatment techniques applied to this condition tend to have an unconfirmed mechanism of action. A hypothesised pathophysiology of LBP indicated to the thoracolumbar fascia, although this currently remains unclear (Langevin and Sherman, 2007, Malanga and Colon, 2010). Similarly,

patients with chronic LBP for longer than 12 months have been found to increase the thickness of their thoracolumbar fascia (Langevin et al., 2009); and the fascia shear strain has been reduced when compared with those without LBP (Langevin et al., 2011). However, neither the causative mechanisms underlying these changes nor the relationship to the symptoms is clear. This pathophysiological difference could therefore potentially suggest a reason for further investigation on the mechanism of action when KT is applied.

The aim of the present study was, therefore, to explore the mechanism of the KT application on the thoracolumbar fascia using a newly developed ultrasound tool. This exploration could provide a better understanding of how the thoracolumbar soft tissue responds to therapeutic taping, which could become a useful guideline for treatment selection. The objectives were to measure soft tissue movement in the thoracolumbar area, and lumbar range of motion when performing the lumbar flexion task with and without KT.

5.1.2 Methods

5.1.2.1 Study design

A snapshot observational study was carried out to develop the methodology and to explore potential taping mechanisms. Asymptomatic participants were recruited to develop an empirical and analytical methodology, and the preliminary results were analysed to ensure the method could be applied to the symptomatic cohort.

Twelve subjects (8 males, 4 females; Age 22.9 ± 3.59; BMI 21.22 ± 2.65), who had no history of LBP or any other chronic pain that had limited their work or daily activities, were invited to participate in the study.

5.1.2.2 General procedure

Participants were asked to perform speed-guided lumbar flexion-extension tasks in two states (without taping and with KT) in the data collection session; the collection procedure is shown in Figure 56. As stated in the methodology (Chapter 4.3.2), participants were advised to perform a speed control experimental lumbar flexion task within 2.5 seconds (four beats from a 90-bpm metronome) and return to a neutral position at the same speed. Participants were allowed to have several practices runs to get familiar with this experimental movement in order to perform the action smoothly and avoid unnatural action or pauses while the exercise was taking place.

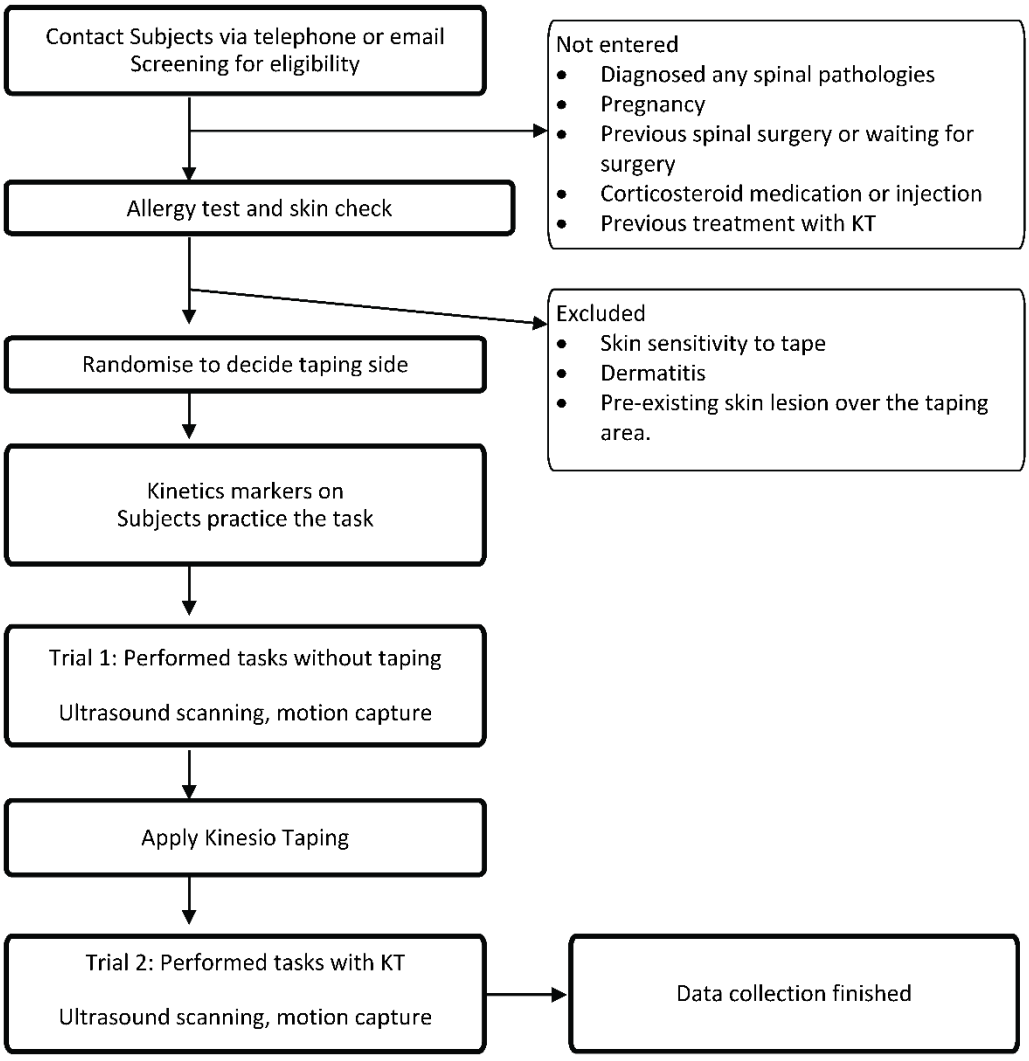


Figure 56. Data collection procedure

5.1.2.3 Taping procedure

KT was applied using I-shape strips taped over one erector spinae muscle, parallel to the spinous process of the lumbar vertebrae (Chapter 4.3.3). The skin condition was checked, and a small piece of KT was then applied to ensure the subject was not allergic to the tape. KT was applied to a single side of the muscle, a computerised random number being used to decide which side to tape. To perform ultrasound scanning, a 5 x 1 cm window beside the L2 and L3 vertebrae was cut on the tape strip (Figure 11).

5.1.2.4 Ultrasound collection

An ultrasound machine (Voluson i, GE Healthcare; WI, USA) with a frequency 4 - 12 MHz linear probe (GE 12L – RS, GE Healthcare; WI, USA) was used to collect data. Parasagittal b-

mode cine ultrasound images of the lumbar tissue movements were collected synchronously with body kinematic data; other detail parameters were stated in the methodology section (Chapter 4.4.1.3.1). Although the taping effect may appear in all areas where KT was applied, this effect can only be observed through a small window due to the probe size. The transducer was placed at a point 3 cm lateral to the middle of the L2 and L3 spinous processes (Figure 11) because the fascia planes are the most parallel to the skin in the higher level of the lumbar area (Langevin et al., 2009) which provided better accuracy of image processing. When performing trunk flexion, the caudal end of the transducer was stabilised on the skin, and the skin was allowed to slide at the rostral end. The overall lateral and rostral translation of the ultrasound transducer was prevented during flexion movement.

5.1.2.5 Motion capture

Active light emitting diodes (LEDs) were attached to the following body landmarks: acromion, the spinal process of seventh cervical and seventh thoracic vertebrae, 10th rib angles, sternal angle, anterior superior iliac spine, posterior superior iliac spine. LED clusters were attached to thighs and shanks (Figure 39). Three extra LEDs were used to monitor the motion of the ultrasound probe and record its orientation. The three-dimensional position of these LEDs was determined with an accuracy of ±1 mm by using a CODA motion analysis system (see 4.4.6.2 for full specification) at a sampling rate of 200 Hz. The range of motion was calculated by processing the marker position retrieved from segment orientations (sum of the trunk and pelvis orientation).

5.1.2.6 EMG collection

Electromyography data was collected synchronously along the ultrasound and motion capture. A linear multichannel EMG electrode arrays were set on the thoracolumbar area of each participant following the instruction stated in Chapter 4.4.5.4.2. All collected data were processed following the procedure stated in the methodology Chapter 4.4.5.5. EMG variables, such as integral of the smoothed EMG signals, root mean square of the EMG signals and mean power frequency of the signals, are presented in two ways in this section. The first part is the difference between two sides, as the volunteers only received KT on one random side when performing designate movement tasks with KT. The second part is the actual value comparisons before and after receiving KT on the same side.

5.1.2.7 Ultrasound tracking algorithm

A customised MATLAB (R2015a, Mathwork; MA, USA) based algorithm was used in the present study. The programme is designed to track fascia movements in 3D ultrasound images using a cross-correlation feature tracking method (Chapter 4.4.1.5.1).

B-mode ultrasound videos were converted into an echogenicity matrix frame-by-frame. An investigator identified boundaries between skin, fascia and muscles according to echogenicity; the intra-investigator reliability of boundary identification was high (ICC = 0.98). The programme then tracked the movements of tissue automatically. The centre area of each layer was defined as an area of interest. The programme automatically searched the contiguous area and detected the movements within every layer. The positions were recorded and the routes of tissue movement were mapped (Figure 20). Further movement calculations, including moving distance and boundary gliding, were carried out according to the map.

5.1.2.8 Paracutaneous tissue translation

This term was used to describe one of the main outcome measures which indicate the relative movements of two tissue layers on each side of a tissue junction boundary, approximately parallel to the skin surface. The detailed definition and the rationale for using this term was stated in the methodology Chapter 4.5.2.1.2.

5.1.2.9 Statistics

Statistical analysis was performed using MATLAB Statistical toolbox (R2015a, Mathwork; MA, USA). Descriptive statistics were used to characterise the study sample. The paired t-test was used to test differences of tissue movements and para-cutaneous translation at boundaries between conditions of no KT application and with KT. Statistical analyses were conducted at a 95% confidence level. P value < 0.05 was considered significant.

In order to inspect if the changes in tissue movement were matching the changes in muscle activation, a Pearson's correlation and regression analysis between integral EMG and tissue movement changes. EMG variable for this analysis was a summary of eight channels; variable for soft tissue movement was summary of tissue movements in four zones during the neutral-to-flexion phase of the movement task.

5.1.3 Results

5.1.3.1 Ultrasound-based tissue observations

Movements of the subcutaneous zone (which contains fat and superficial fascia) were significantly reduced during the lumbar flexion (from neutral to flexion) task when KT was applied (Figure 57A), though no difference was found in skin and muscle movements. Figure 57B revealed the tissue movements when subjects were performing the lumbar extension (return to neutral) task. There were no differences before and after KT was applied.

The inter-tissue para-cutaneous translation in skin-subcutaneous and subcutaneous-fascia boundaries was significantly reduced during the lumbar flexion task when KT was applied (Table 15). Similarly, the para-cutaneous translation was also moderated in the fascia-muscle boundary; however, the difference was not statistically significant ($p = 0.05$). No difference of para-cutaneous inter-tissue translation was found when the subjects performed the return-to-stand task.

No significant difference in ROM was found after KT was applied. The mean lumbar flexion range was 91.19 ± 3.33 degrees before taping, and was 92.47 ± 1.80 degrees after ($p = 0.10$, $df = 11$).

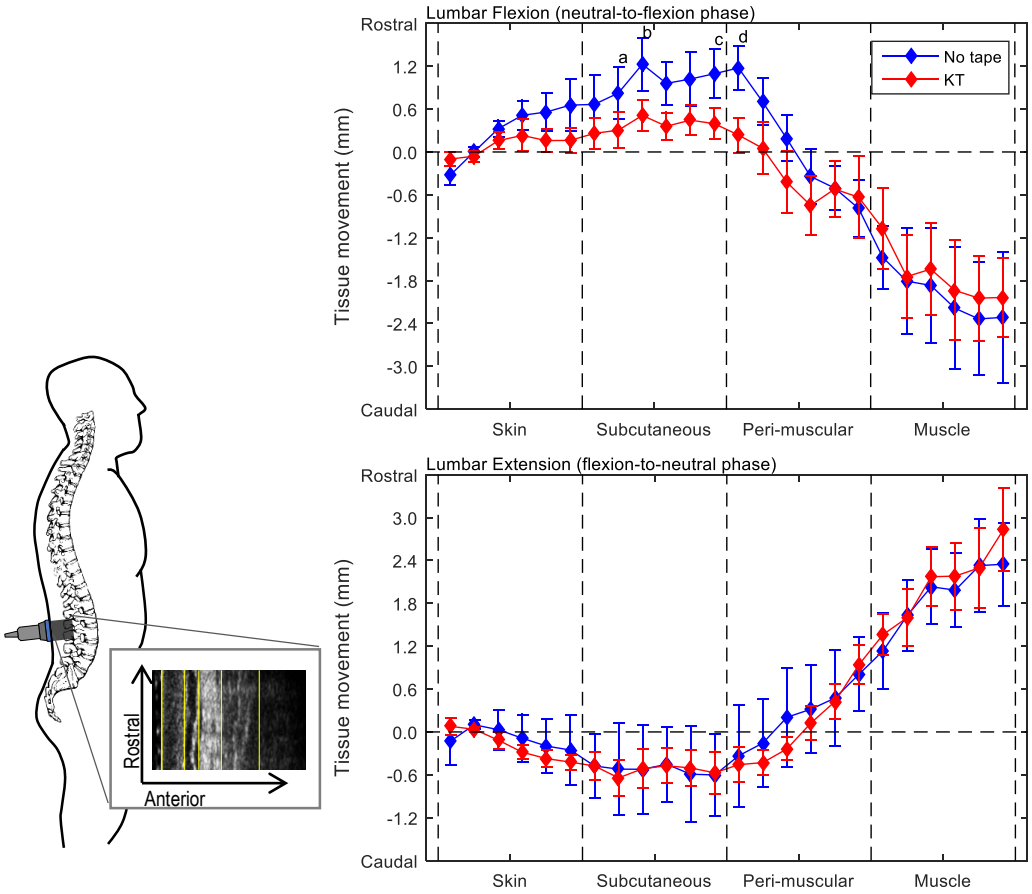


Figure 57. Comparison of tissue movements before and after KT applied.

Red lines represented mean movements when KT was applied, while blue represents data without KT application. Error bars are standard error across 12 subjects. Scale unit: pixels (1 pixel = 0.12 mm). Statistics: a. $p < 0.05$, $T(11) = 1.83$; b. $p < 0.05$, $T(11) = 1.82$; c. $p = 0.03$, $T(11) = 0.63$; d. $p = 0.03$, $T(11) = 1.01$.

Table 15. Para-cutaneous tissue translation comparisons (t-test; unit: pixels)

		NT		KT		
	Interface	Mean	Std.	Mean	Std.	p-value
Neutral to Flexion	Skin/Sub	0.52	0.34	0.27	0.27	<0.01
	Sub/Fascia	0.88	0.74	0.38	0.29	0.02
	Fascia/Muscle	0.94	0.60	0.48	0.42	0.05
Return to Neutral	Skin/Sub	0.35	0.38	0.33	0.49	0.43
	Sub/Fascia	0.52	0.72	0.31	0.20	0.20
	Fascia/Muscle	0.49	0.35	0.60	0.33	0.19

5.1.3.2 Muscle activation

The difference of EMG variables between sides, including integrals, root mean squares and mean power frequency of EMG signals in the neutral-to-flexion and the return-to-neutral phases were summarised in Figure 58 through to Figure 60. Eight channels were plotted according to their relative positions on the thoracolumbar area for visualising muscle

activation patterns during the experimental task. Red data points (KT) represented the differences of EMG variables between sides when KT was randomly applied to one side of the lower back, while blue data points (NT) represented differences of EMG variables between sides when no taping was applied. No significant difference in all three variables were found between the conditions with or without KT when looking at each channel. However, when looked at the comparison across all channels, there are different activation patterns in integral and RMS EMG after taping (Figure 58 and Figure 59).

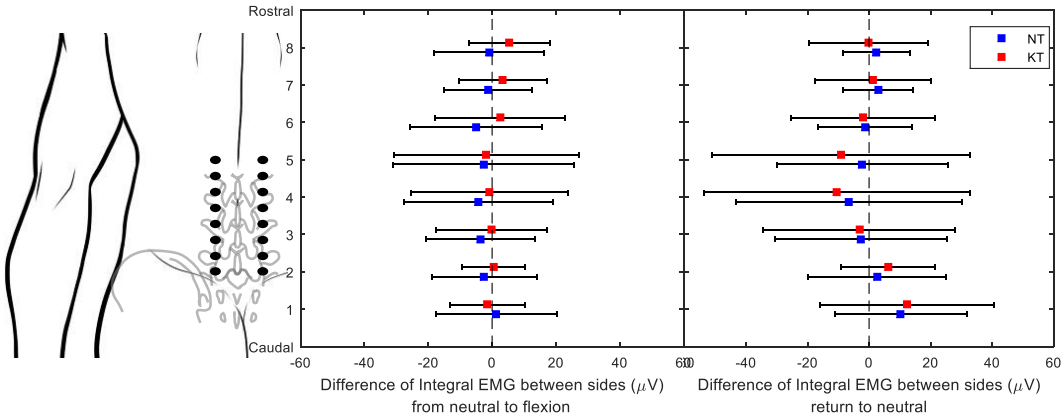


Figure 58. Comparison of integral of smoothed EMG signals between two sides of the lower back.

Red data represented differences of EMG integrals when KT was applied to one side of lower back, while blue data represent differences of EMG integrals between sides when no taping was applied. Error bars are standard deviation across 12 subjects. The y-axis indicates the EMG channels; Channel 1 was placed at the caudal end of the array and channel eight placed at the rostral end of the array.

Comparisons across 8 channels:

Neutral-to-flexion phase: T (7) = -2.94, CI = -6.00 to -0.65, p = 0.02

Flexion-to-neutral phase: T (7) = -1.14, CI = -1.44 to 4.12, p = 0.29

Table 16. Results of paired-t test for Comparison of integral of smoothed EMG signals between two sides of the lower back (n = 12)

Phase	Position	T-value	95% CI		p-value	
Neutral-to-flexion	8	-1.08	-9.09	3.15	0.31	
	7	-2.57	-12.90	-0.91	0.03	*
	6	-1.31	-11.32	2.93	0.22	
	5	-0.30	-7.32	5.58	0.77	
	4	-0.82	-12.41	5.75	0.43	
	3	-0.31	-10.66	8.09	0.76	
	2	-0.97	-9.43	3.65	0.35	
	1	0.23	-6.96	8.55	0.82	
Flexion-to-Neutral	8	0.70	-5.42	10.50	0.50	
	7	-0.19	-12.67	10.73	0.86	
	6	0.31	-9.40	12.45	0.76	
	5	1.12	-6.78	20.83	0.29	
	4	0.62	-13.11	23.21	0.55	
	3	0.63	-11.83	20.93	0.55	
	2	-0.92	-12.40	5.08	0.38	
	1	-0.29	-10.61	8.17	0.78	

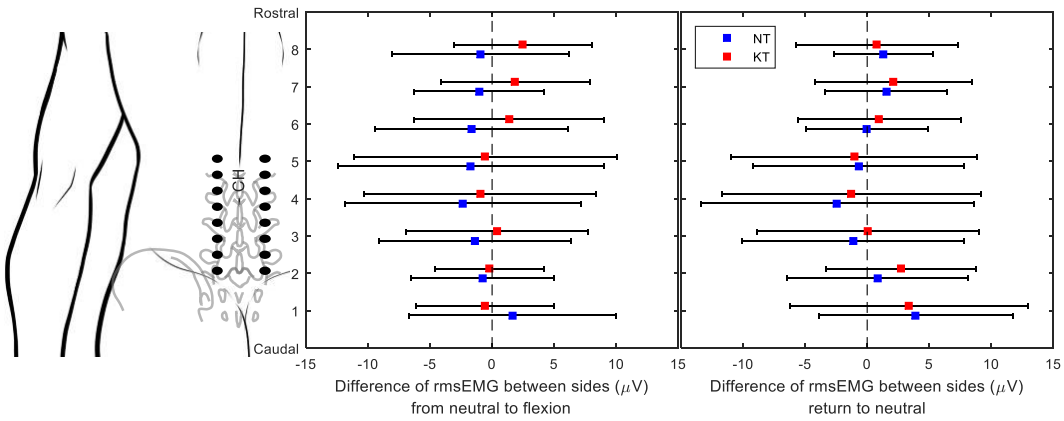


Figure 59. Comparison of root mean square of smoothed EMG signals between two sides of the lower back.
Red data represent the differences of EMG root mean square when KT was applied to one side of lower back, while blue data represent the differences of EMG root mean square between sides when no taping was applied. Error bars are standard deviation across 12 subjects. The y-axis indicates the EMG channels; Channel 1 was placed at the caudal end of the array and channel eight placed at the rostral end of the array.
Comparisons across 8 channels:
Neutral-to-flexion phase: T (7) = -2.35, CI = -3.02 to 0.01, p = 0.05
Flexion-to-neutral phase: T (7) = -1.68, CI = -1.32 to 0.22, p = 0.14

Table 17. Results of paired-t test for comparison of root mean square of smoothed EMG signals between two sides of the lower back

Phase	Position	T-value	95% CI		p-value
Neutral-to-flexion	8	-1.53	-5.14	0.95	0.16
	7	-2.78	-7.15	-0.79	0.02 *
	6	-1.15	-4.84	1.54	0.28
	5	-1.08	-3.50	1.20	0.30
	4	-0.78	-5.28	2.53	0.45
	3	-0.47	-4.84	3.17	0.65
	2	-0.55	-2.95	1.77	0.59
	1	1.12	-1.64	4.98	0.29
Flexion-to-Neutral	8	0.41	-2.27	3.31	0.69
	7	-0.75	-6.13	3.04	0.47
	6	-0.58	-4.35	2.56	0.58
	5	0.25	-2.94	3.71	0.80
	4	-0.33	-6.59	4.88	0.75
	3	0.06	-3.78	3.99	0.95
	2	-1.33	-5.07	1.24	0.21
	1	0.59	-2.22	3.80	0.57

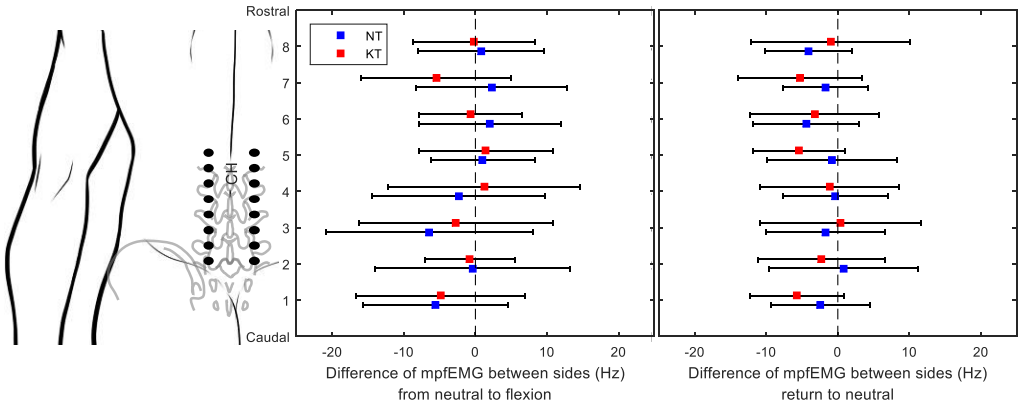


Figure 60. Comparison of mean power frequency of smoothed EMG signals between two sides of the lower back.

Red data represent differences of EMG mean power frequencies when KT was applied to one side of the lower back, while blue data represent differences of EMG mean power frequencies between sides when no taping was applied. Error bars are standard deviation across 12 subjects. The y-axis indicates the EMG channels; Channel 1 was placed at the caudal end of the array and the channel eight was placed in the rostral end of the array.

Comparisons across 8 channels:

Neutral-to-flexion phase: T (7) = 0.33, CI = -2.62 to 3.49, p = 0.75

Flexion-to-neutral phase: T (7) = 1.08, CI = -1.34 to 3.60, p = 0.32

Table 18. Results of paired-t test for comparison of mean power frequency of smoothed EMG signals between two sides of the lower back.

Phase	Position	T-value	95% CI		p-value
Neutral-to-flexion	8	0.32	-5.92	7.90	0.76
	7	2.42	0.69	16.92	0.04 *
	6	0.95	-4.54	11.30	0.36
	5	-0.52	-6.06	3.76	0.61
	4	-1.13	-9.57	3.11	0.28
	3	-0.73	-11.93	6.11	0.48
	2	0.09	-8.15	8.87	0.93
	1	-0.52	-5.84	3.64	0.62
Flexion-to-Neutral	8	-0.80	-11.44	5.33	0.44
	7	2.20	-0.06	8.35	0.05
	6	-0.60	-7.87	4.51	0.56
	5	2.05	-0.35	9.73	0.07
	4	0.10	-5.27	5.75	0.92
	3	-0.73	-7.62	3.89	0.48
	2	1.05	-3.42	9.65	0.32
	1	1.52	-1.81	9.65	0.16

The actual value of EMG variables, including integrals, root mean squares and mean power frequency of EMG signals in the neutral-to-flexion and the return-to-neutral phase, within sides were plotted to demonstrate the effect of KT on these variables (Figure 61 to Figure 63). Eight channels were plotted according to their relative positions on the thoracolumbar

area for visualising muscle activation patterns during the experimental task. Blue data bars (NT) represented EMG variables when volunteers were performing experimental movement tasks with no taping; while yellow data bars (KT) represented variables when volunteers performing the experimental task with KT applied. Although KT increased integrals and root mean squares in almost all positions in both phases after KT was applied, the group means were not significantly different (Table 19 through Table 21).

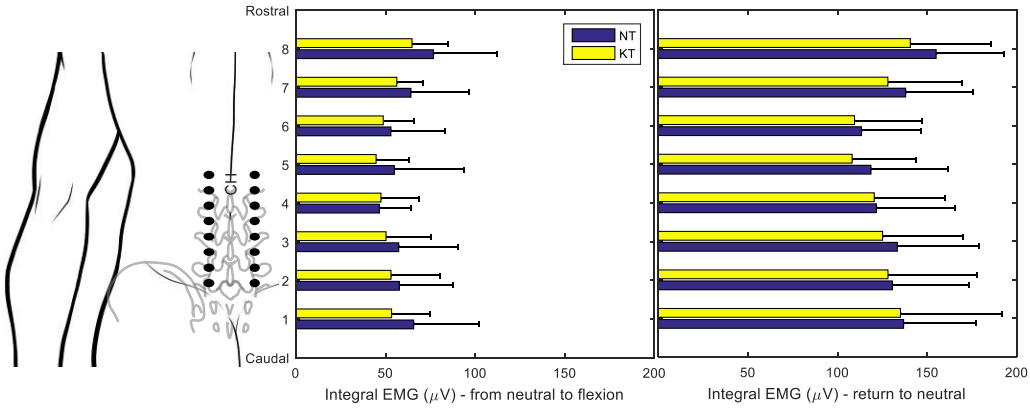


Figure 61. Comparison of integral of smoothed EMG signals before and after KT within the same side.

Blue bars represent integral of smoothed EMG signals when volunteers performing experimental movement task with no taping, while yellow bars represent integral of smoothed EMG signals when volunteers performing the experimental task with KT applied. Error bars are standard deviation across 12 subjects. The y-axis indicates the EMG channels; Channel 1 was placed at the caudal end of the array and the channel 8 was placed in the rostral end of the array.

Comparisons across 8 channels:

Neutral-to-flexion phase: T (7) = 4.56, CI = 3.46 to 10.91, p < 0.01

Flexion-to-neutral phase: T (7) = 3.79, CI = 2.47 to 10.64, p = 0.01

Table 19. Results of paired-t test for comparison of integral of smoothed EMG signals before and after KT within the same side

Phase	Position	T-value	95% CI		p-value
Neutral-to-flexion	8	1.88	-2.06	25.95	0.09
	7	1.20	-6.53	22.25	0.25
	6	1.05	-7.32	20.30	0.32
	5	1.46	-5.20	25.57	0.17
	4	1.12	-3.14	9.53	0.29
	3	0.84	-9.93	21.92	0.42
	2	0.82	-7.80	17.06	0.43
	1	0.74	-6.28	12.55	0.48
Flexion-to-Neutral	8	1.57	-5.73	34.53	0.14
	7	1.03	-11.23	31.11	0.32
	6	0.64	-15.98	28.94	0.53
	5	1.03	-11.98	33.04	0.33
	4	0.44	-18.00	26.82	0.67
	3	0.63	-15.33	27.44	0.54
	2	0.26	-18.67	23.58	0.80
	1	0.08	-20.40	21.92	0.94

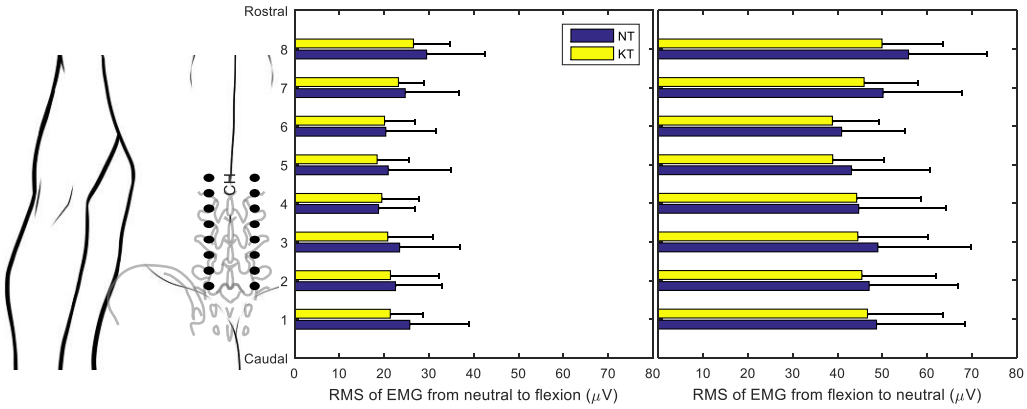


Figure 62. Comparison of root mean square of EMG before and after KT within the same side.

Blue bars represent root mean square of smoothed EMG signals when volunteers performing experimental movement task with no taping, while yellow bars represent root mean square of smoothed EMG signals when volunteers performing the experimental task with KT applied. Error bars are standard deviation across 12 subjects. The y-axis indicates the EMG channels; Channel 1 was placed at the caudal end of the array and the channel eight was placed in the rostral end of the array.

Comparisons across 8 channels:

Neutral-to-flexion phase: T (7) = 3.21, CI = 0.48 to 3.17, p = 0.02

Flexion-to-neutral phase: T (7) = 4.79, CI = 1.58 to 4.66, p < 0.01

Table 20. Results of paired-t test for comparison of root mean square of EMG before and after KT within the same side

Phase	Position	T-value	95% CI		p-value
Neutral-to-flexion	8	1.18	-2.53	8.38	0.26
	7	0.61	-3.94	6.96	0.55
	6	0.59	-4.03	6.91	0.57
	5	1.01	-2.93	7.89	0.33
	4	0.69	-2.04	3.88	0.50
	3	0.80	-3.90	8.29	0.44
	2	0.54	-3.52	5.78	0.60
	1	0.77	-2.91	6.00	0.46
Flexion-to-Neutral	8	1.46	-2.98	14.82	0.17
	7	1.05	-4.61	13.08	0.31
	6	1.05	-3.99	11.14	0.32
	5	1.13	-3.99	12.37	0.28
	4	0.32	-7.90	10.59	0.75
	3	0.95	-4.96	12.36	0.36
	2	0.54	-5.04	8.29	0.60
	1	0.58	-4.62	7.83	0.58

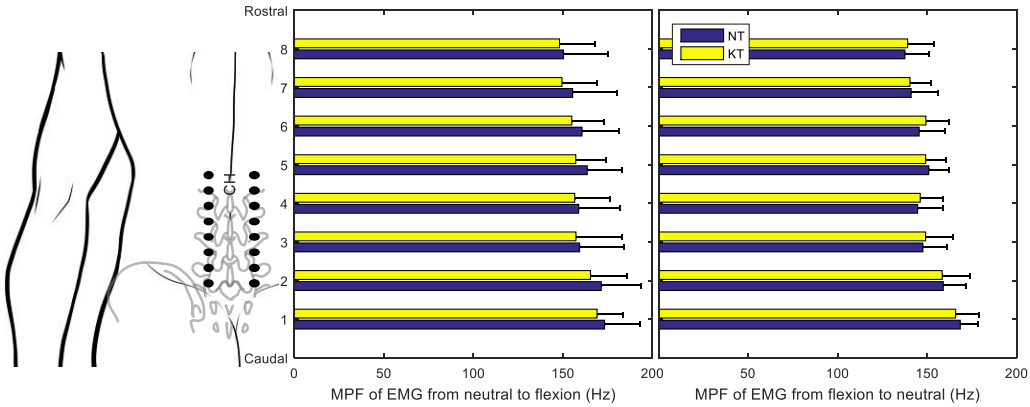


Figure 63. Comparison of mean power frequency of smoothed EMG signals before and after KT within the same side.

Blue bars represent mean power frequency of smoothed EMG signals when volunteers performed the experimental movement task with no taping, while yellow bars represent mean power frequency of smoothed EMG signals when volunteers performing the experimental task with KT applied. Error bars are standard deviation across 12 subjects. The y-axis indicates the EMG channels; Channel 1 was placed at the caudal end of the array and the channel eight was placed at the rostral end of the array.

Comparisons across 8 channels:

Neutral-to-flexion phase: T (7) = 6.39, CI = 2.74 to 5.95, p < 0.01

Flexion-to-neutral phase: T (7) = -0.45, CI = -2.08 to 1.42, p = 0.67

Table 21. Results of paired-t test for comparison of mean power frequency of smoothed EMG signals before and after KT within the same side.

Phase	Position	T-value	95% CI		p-value
Neutral-to-flexion	8	0.51	-7.23	11.62	0.62
	7	1.50	-2.81	14.73	0.16
	6	1.47	-3.10	15.12	0.17
	5	0.99	-5.17	13.47	0.34
	4	0.64	-5.51	9.99	0.53
	3	0.57	-6.25	10.58	0.58
	2	1.84	-1.17	13.20	0.09
	1	1.21	-2.92	9.91	0.25
Flexion-to-Neutral	8	-0.52	-7.98	4.92	0.61
	7	0.27	-4.87	6.26	0.79
	6	-1.10	-10.78	3.66	0.30
	5	0.81	-2.94	6.39	0.43
	4	-0.69	-8.49	4.48	0.51
	3	-0.92	-9.98	4.13	0.38
	2	0.18	-6.64	7.83	0.86
	1	1.22	-1.92	6.61	0.25

5.1.3.3 Correlation between EMG and tissue movements

A scatter plot was generated to demonstrate the relationship between integrated EMG values and soft tissue movements during the experimental task (Figure 64). Positive values on the X-axis of the plot indicate that KT reduced overall tissue movements, and positive values on the Y-axis indicates that KT reduced muscle activation. Therefore, data located in the first quadrant indicate that KT reduced both tissue movement and muscle activation; data located in the third quadrant indicated that KT increased both tissue movement and muscle activation. In contrast, data located in the second and fourth quadrants indicated that tissue movements changes in an opposite direction to the EMG changes. A positive correlation was found between EMG variables and tissue movements ($r = 0.47$, $p = 0.04$), with the majority of the data being located in the first and third quadrants.

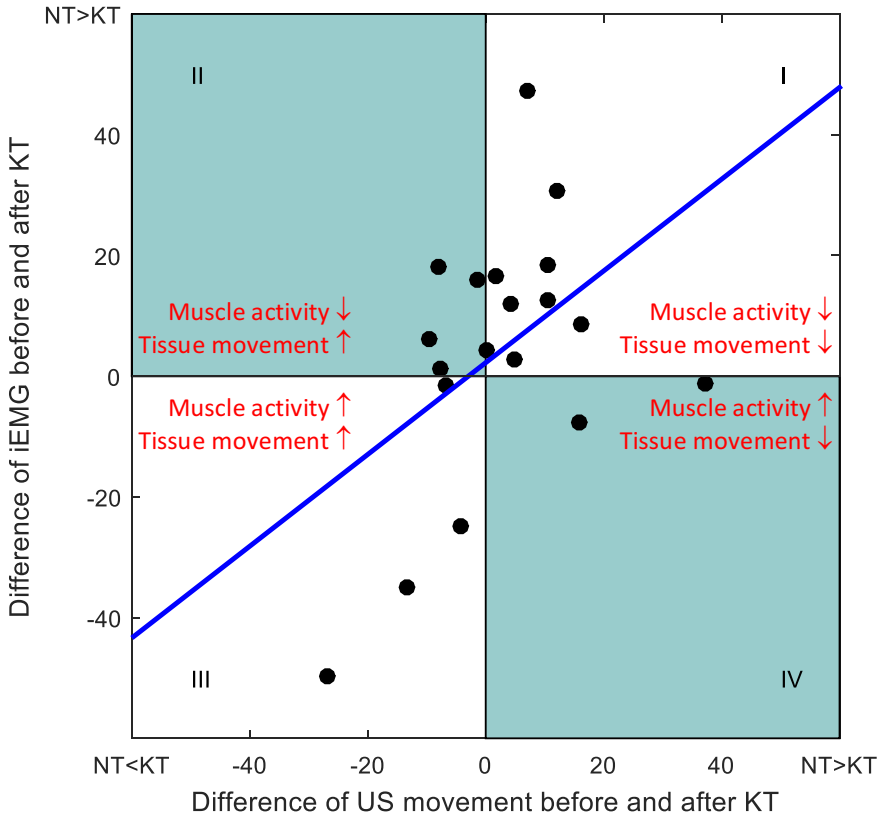


Figure 64. Scatter plot with regression line representing the correlation between tissue movement changes and EMG changes after KT.

US: tissue movements measured by ultrasound method

Increasing value on the X axis indicates that KT reduced tissue movements, and increasing value on the y-axis indicates that KT reduced muscle activation. Therefore, data located in Quadrant I indicate that KT reduced both tissue movement and muscle activation; data located in Quadrant III indicated that KT increased both tissue movement and muscle activation.

(Pearson's $r = 0.47$, $p = 0.04$, regression equation: $\Delta EMG = 0.76 \times$ Tissue Movement + 2.23)

5.1.4 Discussion

The present study aimed to assess the impact of KT on the movements of the thoracolumbar soft tissues. Most studies concentrate on KT's effect on pain and symptoms (Williams et al., 2012). However, the evidence exploring its actual mechanisms is inadequate. It was therefore likely beneficial to understand the effect of KT on the skin and subcutaneous tissues in asymptomatic subjects during whole-body movements, in order to understand mechanisms and perhaps what kind of patients are most likely to benefit - myofascial related LBP for example. By understanding the KT mechanisms in those without pain, we will be able to compare any tissue movement differences observed in people with pain who have KT applied.

The result of the present study shows that KT reduced tissue movements in the subcutaneous zone, which is the area that contains fat tissue and superficial fascia when the subjects were performing lumbar flexion from a neutral position tasks. However, KT did not repeat the alterations when the subjects were performing return-to-stand tasks likely due to irregular movement patterns. Interestingly, alongside the tissue movements being moderated by KT, there were indications of related changes in lumbar muscle activation. These results suggest that KT is likely to change actions of the subcutaneous tissue.

The absence of ROM changes found in the present study do not corroborate the results of the study of Yoshida et al. (Yoshida and Kahanov, 2007), which reported a significant increase in the ROM upon application of KT, instead they support the findings of another KT study (Lemos et al., 2014) which reported no significant immediate improvement of ROM after applying KT. However, evidence on ROM improvement is currently conflicting. The conflict may be due to two reasons: firstly, results were produced by different assessment methods; for example, Yoshida measured the distance between the finger and the toes and Lemos measured distance changes on lower back skin markers (Schober's test), although they both asked participants bend to touch their toes. While in the present study, ROM was calculated by kinematic data (trunk and pelvis orientation). Second, the taping techniques were slightly different in each study. It is therefore difficult to compare results from the different studies, however some studies recommended that analysing trunk movement as a multi-segment enables better understanding of spine kinematics. Our method is, therefore, subtler in that segmental movements were measured and more robust in terms of proven accuracy (Muyor et al., 2017, Pourahmadi et al., 2017).

Information about muscle activity has been considered to confirm changes in tissue dynamics were pairing with any muscle activity changes due to findings in other studies which note an altered muscle activity when KT was applied to the body (Gómez-Soriano et al., 2014, Martínez-Gramage et al., 2016). It has also been suggested that the reduction of para-cutaneous boundary translation may be the result of impaired neuromuscular control and recruitment patterns of muscles during trunk movements. This has been shown to be associated with chronic LBP (Jacobson, 2009, MacDonald et al., 2009), and therefore analysis of this electromyography data could reveal the neuromuscular mechanism of KT. Results suggested that the muscle activation changes were positively correlated with the tissue movement changes which were in agreement with this hypothesis.

There has been some previous research into the effect of KT on anticipatory control of the trunk. However, the evidence is currently conflicting (Bae et al., 2013, Voglar and Sarabon, 2014). Bae et al. reported that the application of KT reduces pain patients with LBP, and this reduction positively affects patients' anticipatory postural adjustment. However, Voglar and Sarabo (2004) reported an earlier onset of muscle activation after both KT and placebo application, but there was no difference between KT application over lumbar paravertebral muscles and placebo application in young healthy participants. While, EMG results of the present project indicated a reduction of muscle activation pattern during the experimental lumbar flexion movements in asymptomatic participants, even though these results were not statistically significant. These observed changes might have clinically applicable value in LBP patients. However, whether the direction of muscle activation changes is beneficial in this case remains uncertain as the current information is inadequate without having further studies of KT application effects on subgroups of patients with LBP.

There were a few limitations in the present study. Firstly, the effect with a sham taping or different application methods were not compared - for example using different direction of tape tension, however, keeping the study procedure as simple as the standard taping method, which was introduced in KT books and prior studies (Added et al., 2013, Kase et al., 2003, Parreira et al., 2014b), provides a clearer and focused view in research findings. Apart from KT, there are also other types of tapes are currently used in the clinical practice, McConnell Tape and Dynamic Tape, for example. Only one particular method of KT was applied in the present study. Therefore it is uncertain if a similar effect can be delivered using different tape or methods. More studies are required to answer this as no studies investigated the effects of taping effects on tissue movements have been published.

Second, in order to capture the ultrasound videos of the taped area, a rectangular portion of the tape was removed to allow placement of the probe. This may have affected the taping effect to the area from which results were retrieved and therefore may have had an impact on overall movement and para-cutaneous translation between layers. Unfortunately, no better method could be applied to avoid cutting a window in the tape, owing to the current limitation of ultrasonography techniques – ultrasonic waves does not penetrate KT. Another potential limitation was that the assessment could only be performed at the level of second and third lumbar spine due to the size of the ultrasound probe view. KT may affect movements of the whole thoracolumbar fascia. Nonetheless, the scanning position was chosen because of the flat surface in this level making the assessment and retrieval of higher quality images easier (Langevin et al., 2009). This may not only warrant further research in areas where mobility is more restricted, but also offer a greater idea of the effects of KT on connective tissue and pathogenesis for LBP (Langevin and Sherman, 2007).

Irrespective of some limitations mentioned above, there is an evident effect of KT on tissue movement [and short conclusion of EMG]. Further observational studies, particularly case series work, are then required in this study area. The key future experiment is a repetition of these measures in patients with LBP. What we would like to observe is what happens to the tissues when some patients benefit or don't benefit from KT based on clinical responses, for example, subjective pain scale assessments, total ROM assessments.

5.1.5 Section summary

In summary, thoracolumbar tissue dynamics were altered in subjects without LBP after receiving KT application. Results suggest that KT may reduce sub-cutaneous connective tissue movements and inter-tissue translation at boundaries during lumbar flexion movement. Additionally, KT may also reduce lumbar muscle activation and the reduction was positively correlated to the tissue dynamics change. However, whether the degree or direction of these changes in tissue movement and EMG may represent a beneficial result after the application of KT remains uncertain.

5.2 Observational laboratory study II – Tissue stiffness

Can Kinesio-Taping alter the stiffness of underlying soft-tissue?

Data in this section was collected from a collaboration project taking place in the Faculty of Sports Science, University of Nantes, France. Therefore, a seaprate group of asymptomatic participants was recruited for this project. People involved in this project have been listed in the originality statement. Analysed data have been presented in the XXVI Congress of the International Society of Biomechanics. Brisbane, Australia. The abstract has been published in the abstract book of XXVI Congress of the International Society of Biomechanics, 2017 (pp.461).

5.2.1 Background

The observational work in the last section (Chapter 5.1) had indicated a reduction in TLF deformation during lumbar flexion when KT was applied in asymptomatic subjects (Tu et al., 2016). This may be considered as a primary mechanism of KT. However, this finding may conflict with the findings published by Langevin et al. (2011) which suggested a 20% decrease in relative movement between skin and muscle during passive lumbar flexion and a subsequent reduction in deformation of the TLF predominantly in people with a history of chronic LBP. Whether the reduction in deformation of the fascia is beneficial remains unclear. These conflicting findings result in a lack of clarity concerning the physiological importance of TLF shear deformation or its potential therapeutic management.

A prospective study has shown that the coracohumeral ligament is stiffer in patients with adhesive capsulitis compared with their unaffected contralateral shoulder (Wu et al., 2015). This study also demonstrated variations in the stiffness of the ligament reflecting different angles of external rotation of the arm. The development of this study potentially adds additional criteria for linking adhesive capsulitis with tissue property changes such as stiffness and thickness of the ligament. Within other fibrosis tissue, the plantar fascia, another study using strain elastography found the plantar fascia in symptomatic patients to be thicker and more hypoechoic compared with controls, correlated with a loss of elasticity, or a harder fascia (Sconfienza et al., 2013). Langevin et al. (2009) found thicker thoracolumbar fascia in patients with chronic LBP with b-mode ultrasound. However, tissue elasticity was not included in their investigation. Looking at the elasticity of thoracolumbar fascia may be a potential approach to clarify the conflicting results of the reduction of para-cutaneous translation in response to KT.

Considering taping, a high quality study reported that a rigid taping technique (Figure 65) thought to 'unload' muscles, affects muscle shear elasticity at rest and during contraction (Hug et al., 2014). Despite taping not having a significant effect on fully contracted or shortened muscle, the shear elastic modulus was significantly affected by the taping treatment when the muscle was moderately stretched, highly stretched and under submaximal contraction in comparison with the no tape and sham tape. Although a different tape type and technique was used in this study, these results indicated that taping can alter tissue biomechanical characteristics. There is no clear evidence demonstrating an association between KT treatment and tissue stiffness.

Figure 65. Taping technique used to de-load thigh muscles in the study of Hug et al. (2014).

Elastography has been described as a method of portraying the elasticity properties of biological tissue (Ophir et al., 1999). The strain of a tissue is its response to an applied force, such as stress or pressure, with both longitudinal and shear components. Among this, the shear strain is the response to angular forces, such as twisting. When a stress is applied to fluids, the pressure is the same in all directions. Hence shear strain and shear waves do not exist in pure fluids (Winn et al., 2016). Biological tissues like muscle, tendon and fascia have both viscous and elastic properties and can, therefore, be evaluated using this technique. The European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) published a guideline summarised basic principles of elastography technique and recommended a number of clinical applications of all forms of elastography (Bamber et al., 2013, Cosgrove et al., 2013). Among these elastography techniques, the shear-wave elastography is a relatively new technique, which quantifies the shear elastic modulus of a localised area of tissue (Bercoff et al., 2004, Shinohara et al., 2010). The shear elastic modulus is calculated from measurements of local shear wave velocity propagation from a remote

mechanical vibration pulse. Ultrasound shear wave elastography provides a reliable measure of muscle shear elastic modulus (Lacourpaille et al., 2012). A linear relation between muscle shear elastic modulus and muscle stress during passive stretching has been reported (Chernak et al., 2013, Koo et al., 2013, Maïsetti et al., 2012), and some correction algorithms have been developed and examined to overcome the bias of applying shear-wave elasticity measurement in thin layer samples (Couade et al., 2010, Mo et al., 2016). This technique, therefore, provides a unique opportunity to quantify the effect of taping on tissue stiffness.

The aim of this project was to investigate the effect of K-tape on TLF deformation during lumbar flexion, to inform efforts to understand taping mechanisms and ultimately target treatment better.

5.2.2 Method

Tissue stiffness was evaluated by measuring shear wave velocity dispersion (Chen et al., 2004). An Aixplorer ultrasonic scanner (V6.0; Supersonic Imagine, Aix-en-Provence, France) coupled with a linear transducer array (4-15 MHz, SL15-4), was used in elastography mode to measure soft tissue shear wave velocity. Fourteen healthy volunteers participated in the present study. Shear wave velocity of two regions of the thoracolumbar tissues was compared: the subcutaneous and deep fascial zones.

Three taping conditions (no KT, KT and sham tape) were examined in a randomised order. KT was randomly applied to one side of the thoracolumbar area following the procedure stated in the methodology section (Figure 11). The sham tape was applied as two small pieces of KT on the top and bottom of the area of interest without any tension, and the direction of tape expansion was not aligned with the direction of tissue movements (Figure 66A). For each condition, volunteers were asked to adopt three postures (0°, 45° and 90° of lumbar flexion, see Figure 66.B&D) in a randomised order. All randomisations were done by using a list of computer-generated sequences.

Due to the limitation of the sampling frequency of shear wave velocity processing, elastography data were obtained from static postures instead of dynamic movement tasks. During the ultrasound scans, the upper body of volunteers was supported by an adjustable box according to their leg length in order to maintain the accuracy of lumbar flexion (Figure 66. C&D).

Tissue layers were identified following the same rules as Chapter 5-1 once the ultrasound image was obtained. The map of shear elastic modulus with the colour scale depicting

graduation of shear elastic modulus were used to obtain a representative value, which was an average value of shear elastic modulus (kPa) over each identified rectangle areas (Figure 67).

A two-way repeated-measures ANOVA was used to test the effects of taping condition and subject posture, with dependent variables being shear wave velocity of the subcutaneous and deep fascial zones. Post hoc least significance difference tests were used when significant main effects were observed, and η2 effect sizes noted. Significance was defined as an alpha of < 5%.

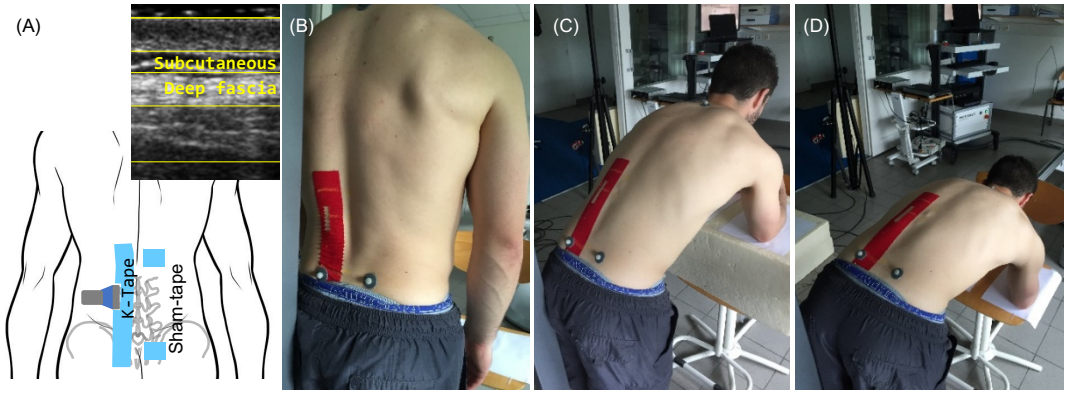


Figure 66. Demonstrations of taping and ultrasound scan positions.

A: demonstration of KT, sham-taping and ultrasound probe position. Example of ultrasound image with annotated tissue layers

B: 0° of lumbar flexion. Volunteers have been provided with a pole as posture reference. They were asked to align their hell, hip and scapular to maintain a straight standing.

C: 45° of lumbar flexion. Volunteers were provided with a box to support their trunk during ultrasound scans

D: 90° of lumbar flexion. An adjustable chair was placed in the same distance as the trunk length of the volunteer, and the chair was adjusted the same height as the leg length of the volunteer to ensure the position of lumbar flexion.

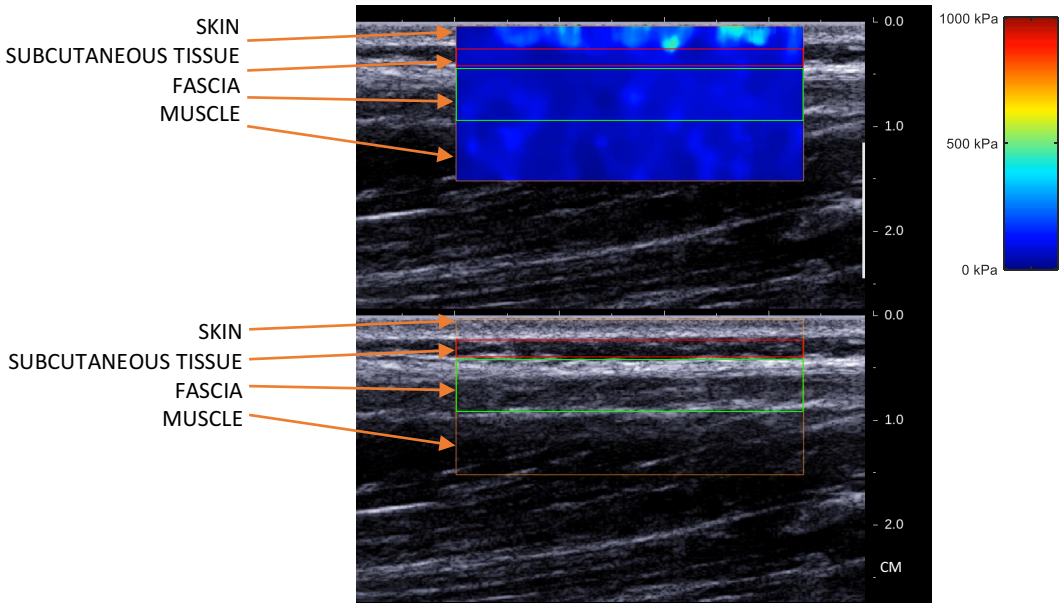


Figure 67. An examples of shear elastic modulus map.

The ultrasound image was obtained during the experiment. B-mode ultrasound image was displayed on the lower panel for data visualisation and tissue layers' identification. The map of shear elastic modulus is superposed onto the B-mode image on the upper panel, with the colour scale depicting graduation of shear elastic modulus (scale (kPa) at top right). To obtain a representative value, the shear elastic modulus (kPa) was averaged over the identified rectangle areas. Only shear elastic modulus in subcutaneous (red) and fascia (green) zones were selected for statistical tests.

5.2.3 Results

Shear wave elasticities were represented by shear wave velocity within the subcutaneous zone and deep fascial zone of thoracolumbar tissue. Values of mean shear wave velocity and standard errors across 14 volunteers for three lumbar postures under three taping conditions were illustrated in Figure 68.

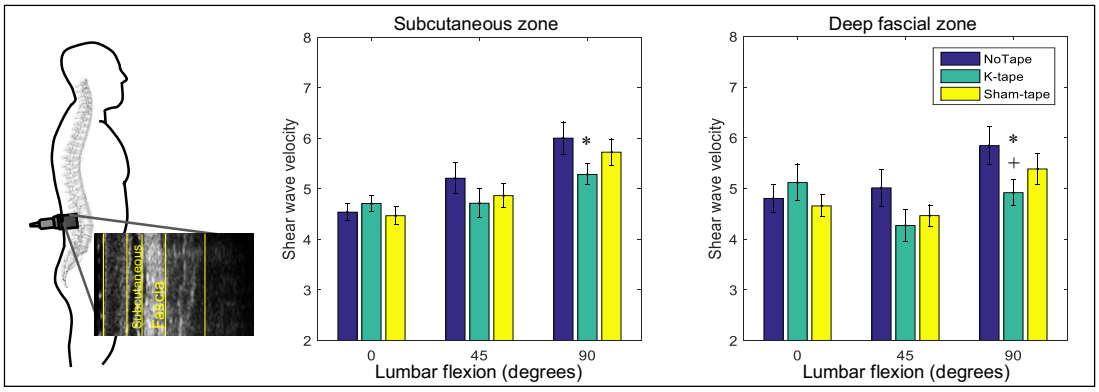


Figure 68. Effect of KT and sham tape on the thoracolumbar tissue shear elasticity.

** p < 0.05 for comparison of K-Tape and no tape;*

+ p < 0.05 for comparison of K-tape with sham tape.

Shear wave velocity increased in both the subcutaneous ($F = 17.30$, $p < 0.01$, $\eta^2 = 0.57$) and deep fascial zones ($F = 7.59$, $p < 0.01$, $\eta^2 = 0.37$) when lumbar flexion degree increased, irrespective of tape condition. When KT was applied, there was a trend towards reduced shear wave velocity across the TLF, with a significant reduction in stiffness in 90° of lumbar flexion in both the subcutaneous zone ($T = 2.06$, $p = 0.03$) and the deep facial zone ($T = 2.30$, $p = 0.02$). Sham taping showed, no differences from no taping, but a significant increase in shear wave velocity at 90° of flexion was found in comparison with KT ($T = 1.79$, $p = 0.048$).

A particularly interesting finding was the significant interaction between posture and taping on shear wave velocity ($F = 4.36$, $p = 0.04$, $\eta^2 = 0.25$). Which implies that fascia stiffness is no longer positively correlated with tissue length when KT is applied.

5.2.4 Discussions

This observational work aimed to assess the effect of KT on the biomechanical property of the thoracolumbar tissue to discover the actual mechanism of KT, as a gap of evidence on the mechanism of this treatment has been identified in the earlier part of this thesis (Chapter 1). Results of the first study (Chapter 5.1) showed a decrease of translational movements when volunteers are performing lumbar movements with KT. These results are likely to be conflicting with the result of ultrasound-based observational work done by Langevin et al. (2011), which revealed a similar reduction in tissue deformation when people with LBP received a passive lumbar movement. This additional observation provides a different aspect of examining tissue biomechanics. Understanding the effect of KT on tissue elasticity in participants without pain plays an important role in finding potential explanations for the conflicting results. Furthermore, comparison of para-cutaneous translational movements and tissue elasticity may help us to understand pain mechanisms and response characteristics, therefore improving the accuracy of treatment decisions concerning KT application.

The result of this experiment shows that increasing degrees of lumbar flexion enhanced shear wave velocity in both the subcutaneous ($p < 0.01$) and deep fascial zones ($p < 0.01$), irrespective of tape condition. This is indicative of increased thoracolumbar fascia stiffness with flexion. This stress-strain elasticity corresponds with a three-dimensional mathematical model, developed by Chaudhry et al. (2008), for exploring the relationship between mechanical forces and deformation of human fasciae. A similar model was also shown on plantar fascia and Achilles tendon (Cheung et al., 2006).

When KT was applied, there was a trend towards reduced shear wave velocity across the thoracolumbar fascia, with a significant reduction in stiffness at 90° of lumbar flexion in both the subcutaneous ($p = 0.03$) and the deep fascial zones ($p = 0.02$). Although not statistically significant, tissue stiffness was increased in both thoracolumbar fascia zones when volunteers were standing with KT applied. Sham taping showed no differences from no taping, but a significant increase in shear wave velocity at 90° of flexion was found in comparison with KT ($p = 0.048$). A particularly interesting finding was the significant interaction between posture and taping on shear wave velocity, which implies that fascia stiffness is no longer positively correlated with tissue length when KT is applied. Although changes before and after taping were not significant, these results corresponded with the previous study which reported that the tissue biomechanics could be influenced by the force input on the skin (Hug et al., 2014).

Notably, soft tissues were less elastic in a neutral position and more elastic in 90 degree of flexion when KT was applied in comparison with no taping. These elasticity changes can be linked with tissue deformation as the recoiling of the tape causing the underlying skin convolutions, which were described as 'lifting' by Kase et al. (2003). However, a simple theory of skin lifting mismatched the elasticity changes in two directions. Pamuk and Yucesoy (2015) found skin lifting and compression within two areas of under the same taping area at the same time. This indicated that applying the same taping tension on different parts of the skin can impose loads differentially within the tissues, and the tissue reaction depends on the mechanical structure of the tissue. Collagen bundles have increasingly random orientations from superficial to deeper layers of the skin (van Zuijlen et al., 2003). Superficial fascia is continuous with the dermis, and consists of connective tissue, both containing irregularly arranged collagen fibres. This is continuous with epimysium of the deeper tissues, including deeper fascia and muscles, below is comprised of irregularly arranged collagen fibres (Langevin and Huijing, 2009). Regarding present findings, I suggest a potential explanation. KT may deform the superficial skin predominantly in the direction it adheres, and therefore generate skin convolutions. Owing to the irregular arrangement of collagen fibres deeper within the skin and within the interlayer connective tissues, the loads are directed diversely such that most of the deformation occurs in arbitrary directions. The tension of KT lifting the skin in the sagittal plane (as the direction of KT application) and concentrating the tissue towards the recoil centre in the frontal plane (parallel to the skin surface). This deformation potentially affected the elasticity of tissues as when the participant was stand, the tissue was stacked and therefore have a higher density.

There were a few limitations in the present project. Firstly, no movement was involved during the experimental procedure; participants were asked to adopt a still posture when receiving ultrasound scans. This is due to the design limitation of the shear wave electrography unit and algorithm. The ultrasound generated a 1 Hz pulse alongside with b-mode ultrasound wave to calculate tissue elasticity. Only slow movement can be observed with this design, and performing active lumbar flexion at such a slow pace is almost impossible to reliably reproduce. Second, even though sham taping was compared with KT, other potential types of tapes were not included in the observation. However, keeping one tape kept the simplicity of the project, and also avoided fatigue effects caused by repeating the same movements multiple times. Between-subject comparison is preferable to answer the research question, however, due to the time limit and collaboration arrangement of this project, I was unable to recruit participants with LBP. The other limitations of taping and ultrasound studies, such as probe size and cutting proportion on tape for scanning purpose, were similar to the other project of my PhD and had been carefully considered and controlled.

5.2.5 Section summary

This is the first study to investigate the mechanical effects of KT in the thoracolumbar fascia using elastography. Results showed that KT significantly reduced thoracolumbar fascia stiffness when the participants were fully flexed. This finding provides a potential explanation for those reported taping effects, such as pain reduction and movement improvement. Further investigation is needed to test if results differ in a symptomatic cohort.

5.3 Chapter summary

Two ultrasound-based tools were used to assess different aspects of tissue biomechanics during lumbar movements before and after KT application in asymptomatic participants. The results suggested that KT was able to change tissue movement, deformation and stiffness during a specific movement. Despite the statistics may have power concern, results showed some reductions in EMG frequency and amplitude and changes of EMG integral were found positively correlated with the changes of tissue movements after taping. This correlation may explain why KT sometimes improves muscle force output. A small ROM improvement were found after taping although this did not reach significant level. The combined result of such minor ROM and muscle activation change may provide an ‘easier-to-move’ feeling. This could be the reason of KT receiving high demand in sports and clinics. The findings of this chapter demonstrated a potential direction to discover the actual mechanism of KT, more evidence

with strong statistical power on people with LBP is therefore required to answer the research question fully.

CHAPTER 6 PILOT OBSERVATIONAL STUDY ON PARTICIPANTS WITH LBP

6.1 Background

In the last chapter, potential mechanisms of KT in the thoracolumbar area were identified, as the tissue dynamics changed when KT was applied to asymptomatic participants. These tissue movement changes were positively correlated with muscle activation level changes although the comparison of EMG amplitude and frequency before and after KT were marginally significantly different (Chapter 5.1.3.2). However, conclusions of relevance to clinical populations cannot be drawn before the repetition of those measurements in people with LBP.

Lumbar flexion, or bending forward, is a common movement performed in daily life as well as many different occupations and sports. It is known to be provocative for many lumbar pain presentations (D'hooge et al., 2013, Geisser et al., 2004, Snook et al., 1998). Previous studies have suggested that lumbar flexion is associated with increased intradiscal pressure that predisposes vertebral discs to injury (Nachemson, 1981, Sato et al., 1999, Yip et al., 2004). Although a systematic review indicated that there are no high-quality studies to associate bending and twisting with LBP (Wai et al., 2010), lumbar flexion triggers a greater amount of thoracolumbar tissue movement in the sagittal plane than extension, side-flexion (coronal plane) or rotation (transverse plane). It has been used in the study of tissue dynamics. For example, Langevin et al. (2011) used a motorised plinth to passively move the trunk to create passive lumbar flexion when investigating the difference in the thoracolumbar tissue dynamic between people with and without LBP. Using passive movement has the advantage of creating a reproducible rate and amplitude of motion while also facilitating stabilisation of an ultrasound probe on the skin. However, active movements were considered more relevant for the task of investigating the KT mechanisms, because KT was designed to facilitate or inhibit tissue movement during functional movement (Kase et al., 2003).

Apart from simple lumbar flexion, other conditions and postures such as sitting and weight carrying were also considered in the experimental design. These conditions are believed to be correlated with LBP, as such postures and activities change the loading on the vertebral bodies and discs (Nachemson, 1981, Wilke et al., 1999). For example, the spine receives 1.5 to 2.5 times the load when compared to standing in a neutral posture; 1.75 to 2 times when

flexing from sitting ; and up to 4 times the load when carrying a 10 kg object (Wilke et al., 1999). These conditions were included in the data collection procedure to observe whether different or similar effects of KT were observed.

LBP has an estimated prevalence of 80% in the general population. Even though 90% of patients recover within six weeks, up to 60% of patients go on to suffer from recurrent episodes (Lemos et al., 2014). LBP is a largely self-limiting condition, but it is responsible for a substantial socioeconomic burden and accounts for one of the highest numbers of disability-resultant reduction in quality adjusted life years globally (Vos et al., 2012). The use of a range of adjunctive therapeutic interventions, such as KT, are popular and believed to offer some level of clinical benefit (Kachanathu et al., 2014), but the actual effects and mechanisms remain unclear. Although potential mechanisms have been discovered in the studies included in Chapter 5, we still lack measures in relevant clinical populations to understand whether the changes in soft tissue movement and muscle activation are beneficial to patients with LBP.

KT is a therapeutic tape with elastic mechanical properties, described as being similar to skin, used to treat a range of musculoskeletal conditions, including LBP (Kachanathu et al., 2014, Mostafavifar et al., 2012). Like the effects on pathology, the claimed similarity to skin has not been proven. The real merits of KT have however been questioned, and its mechanism of action is poorly understood (Morris et al., 2013, Mostafavifar et al., 2012). The multifactorial aetiology of LBP further complicates this issue (Langevin and Sherman, 2007). To help to clarify this issue, this chapter aimed to explore how KT would affect tissue movements during different movement tasks in people with LPB. The objectives are to repeat the same experiment as Chapter 5-1, and additionally apply them to three more conditions which simulate common activities of daily life scenarios such as sitting, holding objects and seeking support during lumbar movements, in addition to the standard movement task. Measurement alongside with this everyday functional movements can then provide a potential direction to judge whether KT has potential clinical relevance or should be left out in the future clinical approach.

6.2 Methods

6.2.1 Study design

Following the asymptomatic observational study, a snapshot repeated-measured observational study was carried out to explore potential taping mechanisms in the thoracolumbar area when volunteers were performing experimental tasks in a series of

conditions designed to mimic daily lumbar motions. Adults with a history of non-specific LBP were eligible for inclusion. Participants with previously diagnosed spinal pathologies were excluded as the pathophysiology of these conditions likely differs to that of non-specific LBP. Participants who had previously been treated with corticosteroids or spinal surgery were also excluded, as this might influence soft tissue dynamics. Detailed inclusion and exclusion criteria are stated in the methodology Chapter 4.2.2, participants included in this chapter were either currently suffering from LBP or have recurrent LBP history. Sixteen participants (9 males, 5 females; Age 22.4 ± 1.0; BMI 24.0 ± 1.65), who had a history of LBP, and met the inclusion and exclusion criteria (Table 2) were invited to participate in the study.

6.2.2 General procedure

The Oswestry LBP disability questionnaire (Fairbank and Pynsent, 2000) was used to assess the history and severity of participants' LBP at baseline. Participants were required to perform the speed-guided lumbar flexion-extension task without taping and with KT in four different conditions (Table 22). The order for these conditions was randomised by sealed envelope selection. Participants were asked to select one envelope from four unmarked identical envelopes to determine the order in which they would perform the movement tasks. Each task was performed three times without KT and repeated a further three times with KT applied. Participants were asked to record their pain after each task using a 10cm Visual Analog Scale (VAS) for pain (Hawker et al., 2011).

Table 22. Movement tasks performed by each participant

Movement Task	Description	Situation
Standard	From neutral to flexion, then return to neutral	Normal condition
Seated	Lumbar flexion when sitting on a stool	Minimize hamstring involvement
With Load	Flexion from standing holding 7.5 kg kettlebell	Simulate daily movement when carrying light objects
With Support	Flexion from standing, a stool support body weight at the end of the motion.	Simulate protective behaviours

6.2.2.1 Neutral lumbar flexion

Volunteers performed the same task as the experimental movements in the asymptomatic participant observational study. They stood in a neutral position, and were asked to try to touch their toes or as close as possible.

6.2.2.2 Seated lumbar flexion

The volunteers were asked to sit on a stool. They were then asked to touch the floor during data collection. This movement may happen in ordinary daily life. As the pelvis was in a fixed position, lower limb involvements were minimised (Figure 69).

Figure 69. Demonstration of lumbar flexion task in the seated condition
Left: initial neutral posture; right: end of flexion posture

6.2.2.3 Lumbar flexion with extra load

Volunteers were asked to perform the standard lumbar flexion task with a 7.5 kettlebell carried by both hands. Carrying objects is a common circumstance in daily lives of human. Form the biomechanical point of view, flexion with load can increase tissue tension in the thoracolumbar area, as the load and the tissue are located on either side of the fulcrum. It was, therefore, worth exploring if soft tissue behaves differently in this challenging condition (Figure 70).

Figure 70. Demonstration of lumbar flexion task with extra load
Left: initial neutral posture; right: end of flexion posture

6.2.2.4 Lumbar flexion with support

On the opposite of flexion with the extra load, volunteers were provided with a stool to support their body weight at the end of lumbar flexion. This support can reduce the loading tension on the soft tissue in the thoracolumbar area. This is also a common way of compensating when LBP occurs (Figure 71).

As stated in the methodology chapter, a metronome set at 90 beats-per-minute was used to guide speed; participants were required to finish each flexion movement in four beats and return to a neutral position at the same speed. Each task was demonstrated carefully to participants, and participants were given sufficient time to practice each movement prior to taking the experimental measurements to ensure they could perform the action smoothly and avoid unnatural action or pauses while the exercise was taking place. The speed and ROM differed slightly between participants, but recorded kinematic data from motion capture allowed for later normalisation. All data were analysed using a normalised registration of posture.

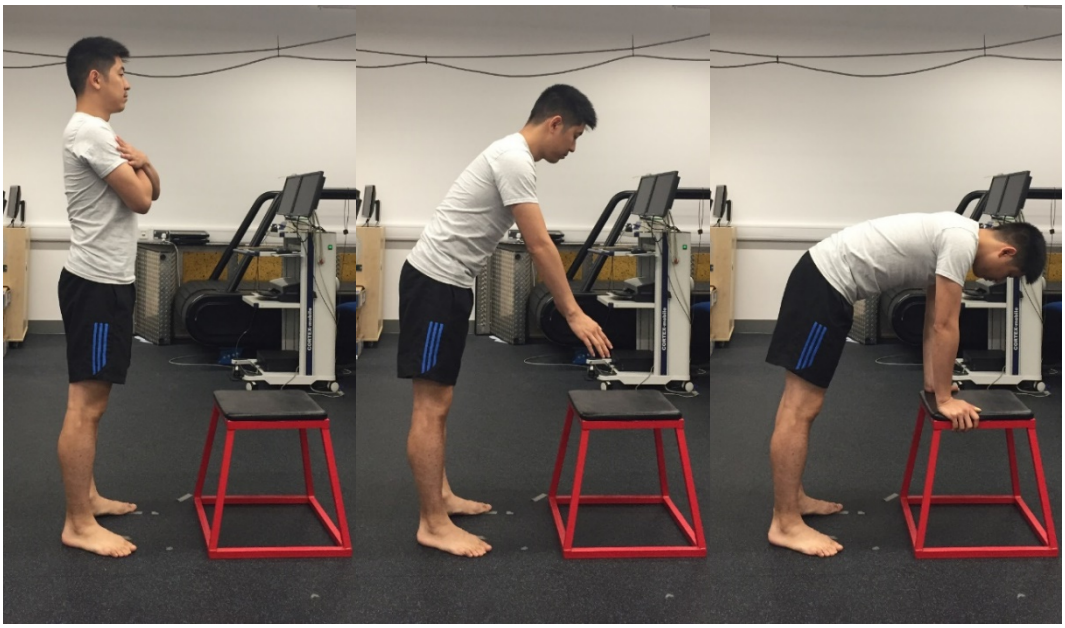


Figure 71. Demonstration of lumbar flexion task in the body weight supported condition
Left: initial neutral posture; right: end of flexion posture

6.2.3 Taping procedure

KT was applied using I-shape strips taped over one erector spinae muscle, parallel to the spinous process of the lumbar vertebrae (Figure 11). The skin condition was checked and a small piece of KT was applied to ensure the subject was not allergic to the tape. KT was applied to a single side of the thoracolumbar area; two identical unmarked sealed envelopes were used to randomly decide which side should first receive KT. Volunteers were asked to choose one envelope after providing consent to participate in the study. A 5 x 1 cm window beside the L2 and L3 vertebrae was cut on the tape strip to allow ultrasound scans.

6.2.4 Data collection settings

An ultrasound machine (Voluson i, GE Healthcare; WI, USA) with a high frequency 4 - 12 MHz linear probe (GE 12L – RS, GE Healthcare; WI, USA) was used synchronously with a motion analysis system (CX-1 units and software, Charnwood Dynamics Ltd., Leicestershire, UK) at a sampling rate of 100 Hz to collect data in this study. All the device settings, including ultrasound scanning procedures and marker placement of motion capture, followed the procedures described in the methodology Chapter 4.4.6.2.3.

6.2.5 Decision of include/exclude EMG data

Unlike chapter 5, the multi-channel EMG data was not reported in this chapter due to the following reasons. Firstly, the Refa64 system was inoperative on two occasions due to multiple components breaking down as a result of high operative demand and aging of the dielectric component. To avoid losing all recruited participants, I decided to carry on the

experiment without EMG collection, to ensure the project finished on time. Sufficient ultrasound and kinematic data were collected despite the absence of EMG data.

6.2.6 Data processing

Customised MATLAB (R2013a – R2015b, Mathworks; MA, USA) based programmes were used to process all data before performing statistical analysis. A cross-correlation feature searching algorithm (Section 4.4.1.5.1.1 on page 56) was used to extract tissue movements in 3D ultrasound images. Tissue movements, including para-cutaneous translation at boundaries, were extracted from the result of feature searching following the algorithm described in the methodology chapter (Section 4.5.2.1 on page 102).

The relative movement between the upper trunk and pelvis were calculated to represent participants' overall lumbar range of motion while performing experimental tasks in each condition. The range of motion (ROM) was extracted by comparing the angle of adjacent segments between the neutral and end of flexion positions in each task condition.

6.2.7 Statistics

Statistical analysis was performed using MATLAB Statistical toolbox (R2015a, Mathwork; MA, USA) and SPSS version 23.0 (IBM Corp, New York, USA). Descriptive statistics were used to characterise the study sample. Two–way Multivariate Analysis of Variance (MANOVA) with repeated measures was used to detect changes in tissue movements and para-cutaneous translations before and after KT was applied. In order to detect if people with LBP respond to KT equally to those who are asymptomatic, data collected in the normal conditions in the present chapter was combined with the data collected for Chapter 5. Pillai's trace was applied as it was designed to overcome the issue that MANOVA assumption of homogeneity of variance-covariance can be violated by a small sample size (Pillai, 1955). Data collected in the other three additional conditions were analysed on their own without comparing with asymptomatic participants (one-way MANOVA).

6.2.8 Potential sub-group exploration

The VAS score during usual lumbar flexion task was used to divide participants with LBP into two subgroups, namely responders and non-responders. Six participants who reported their pain reduced after receiving the KT application (reduction range from 0.4 to 1.6 cm) were considered as responders, the other nine were considered as non-responders. A multivariate analysis of variance (MANOVA) was used to detect any difference between the two subgroups.

6.3 Results

6.3.1 Tissue movements and para-cutaneous translation at the tissue interfaces

6.3.1.1 Usual lumbar flexion

Total tissue movements in the sagittal plane during the normal lumbar flexion task were plotted against normalised depths of the ultrasound image and tissue zones to compare the movement trend of tissues before and after KT (Figure 72). Descriptive statistics of all dependent variables were summarised in Table 23.

The Neutral-to-flexion phase

There was a significant difference in the linear combination of all the dependent variables, which include movements in the four tissue zones, and para-cutaneous translations at the three tissue interfaces between subjects with and without LBP (Pillai's trace = 0.45, F (7, 23) = 2.68, p = 0.03). There were no significant differences in the linear combination of all dependent variables before and after receiving KT (Pillai's trace = 0.31, F (7, 23) = 1.45, p = 0.24) irrespective of group. The impact of Interaction between Taping and LBP was also non-significant in the linear combination of all dependent variables between people with and without LBP (Pillai's trace = 0.37, F (7, 23) = 1.92, p = 0.11).

Follow-up separate univariate ANOVAs on the outcome variables revealed that KT did not affect tissue movement measurements across all subjects after taping irrespective of groups. However, there was a trend towards there being an interaction between taping and LBP condition affecting soft tissue movements. KT decreased the sub-cutaneous tissue movement by 1.21 mm in participants without pain but increased by 1.28 mm in those with pain (F (1) = 3.21, p = 0.08). Similarly, in the fascia zone, KT inhibited tissue movements towards rostral direction by 0.93 mm in asymptomatic participants while facilitated tissue movement towards head by 1.02 mm (F (1) = 4.11, p = 0.05).

Despite the fact that no effects were detected in para-cutaneous translation, neither, there was also a trend towards there being an interaction between taping and LBP condition affecting the para-cutaneous tissue translation at the boundaries between the skin and superficial fascia, where KT decreased the tissue translation in asymptomatic participants by 0.32 mm while increased 0.07 mm in LBP participants (F (1) = 3.19, p = 0.08). A similar trend was also shown at the interface between superficial and deeper fascia, KT decreased the tissue translation in asymptomatic participants by 0.27 mm but increased by 0.36 mm in LBP participants (F (1) = 3.94, p = 0.06).

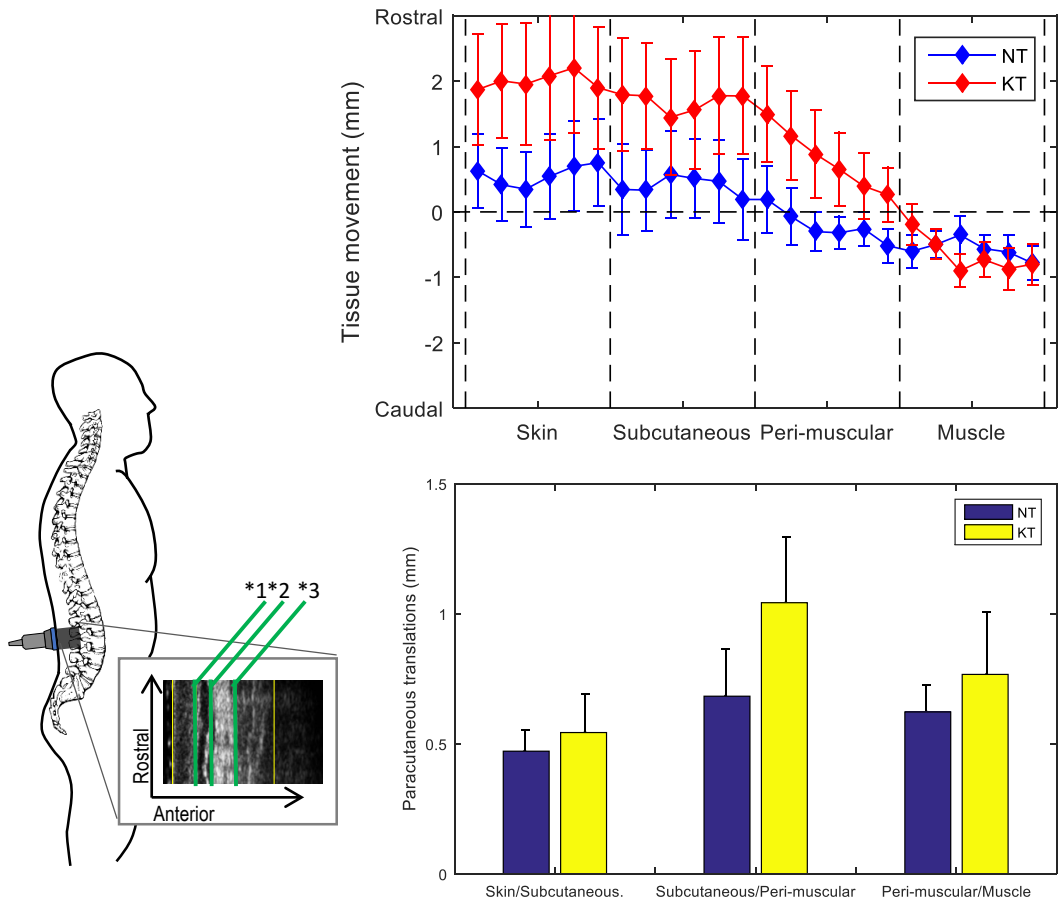


Figure 72. Comparison of tissue movements and para-cutaneous translation before and after KT application – usual condition

Left: *demonstration of ultrasound scanning position, the orientation of the ultrasound image and the location of four tissue zones. *1: the boundary between skin and subcutaneous zones; *2: the boundary between subcutaneous and peri-muscular zones; *3: the boundary between peri-muscular and muscle zones.*

Top right: *tissue movements in the sagittal plane are plotted n the y-axis and zones of the soft tissue on the x-axis (depth) during the neutral to flexion movement phase.*

Bottom right: *para-cutaneous tissue translation in the phase of neutral to flexion.*

NT = no tape; KT = K-tape*.*

Table 23. Descriptive statistic of data for all variables entered into the multivariate test – standard task neutral-to-flexion phase.

positive values in movements indicated KT increased movements toward the rostral direction, while negative values indicated KT increased movements toward caudal direction; positive values in para-cutaneous translations indicated KT increased tissue translation while negative values indicated reductions; Measurement unit: mm

Measure	LBP	Taping	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
M1	Asymptomatic	NT	2.27	0.70	0.83	3.70
		KT	1.43	0.72	-0.03	2.90
	LBP	NT	0.56	0.73	-0.92	2.05
		KT	2.00	0.74	0.49	3.52
M2	Asymptomatic	NT	2.61	0.73	1.11	4.11
		KT	1.40	0.68	0.01	2.80
	LBP	NT	0.40	0.76	-1.15	1.95
		KT	1.69	0.70	0.25	3.13
M3	Asymptomatic	NT	1.53	0.56	0.39	2.68
		KT	0.61	0.47	-0.36	1.57
	LBP	NT	-0.21	0.58	-1.39	0.97
		KT	0.81	0.49	-0.18	1.80
M4	Asymptomatic	NT	-0.62	0.21	-1.03	-0.20
		KT	-1.01	0.23	-1.48	-0.53
	LBP	NT	-0.57	0.21	-1.00	-0.14
		KT	-0.66	0.24	-1.16	-0.17
P1	Asymptomatic	NT	0.61	0.10	0.40	0.83
		KT	0.29	0.11	0.07	0.51
	LBP	NT	0.47	0.11	0.25	0.69
		KT	0.54	0.11	0.32	0.77
P2	Asymptomatic	NT	0.73	0.15	0.43	1.02
		KT	0.46	0.18	0.09	0.82
	LBP	NT	0.68	0.15	0.38	0.99
		KT	1.04	0.19	0.66	1.42
P3	Asymptomatic	NT	0.80	0.12	0.56	1.05
		KT	1.20	0.24	0.71	1.69
	LBP	NT	0.62	0.12	0.37	0.88
		KT	0.77	0.25	0.27	1.27

M1 = skin movement; M2 = subcutaneous zone movement; M3 = fascial zone movement; M4 = muscle zone movement; P1 = para-cutaneous translation at interface between skin and subcutaneous zone; P2 = para-cutaneous translation at interface between subcutaneous and facial zone; P3 = para-cutaneous translation at interface between fascial and muscle zone. NT = no tape; KT = K-tape. Positive values indicated the tissue moved to rostral direction, while negative value indicated the tissue moved to caudal direction.

The return-to-neutral phase

Descriptive statistics of all dependent variables were summarised in Table 24. No significant difference was found on the linear combination of all the dependent variables, which include movements in the four tissue zones, and para-cutaneous translations at three interfaces between subject with and without LBP in the phase of return-to neutral (Pillai's trace = 0.25, F (7, 21) = .99, p = 0.45). There were no significant differences in the linear combination of all dependent variables before and after receiving KT in the return-to-neutral phase (Pillai's trace = 0.21, F (7, 21) = 0.81, p = 0.59), nor was there any interaction between Taping and LBP found in this phase (Pillai's trace = 0.10, F (7, 21) = 0.34, p = 0.93). Follow-up univariate separate univariate ANOVAs on the outcome variables revealed that there were no significant differences in the ultrasound data collected in the return-to-neutral phase.

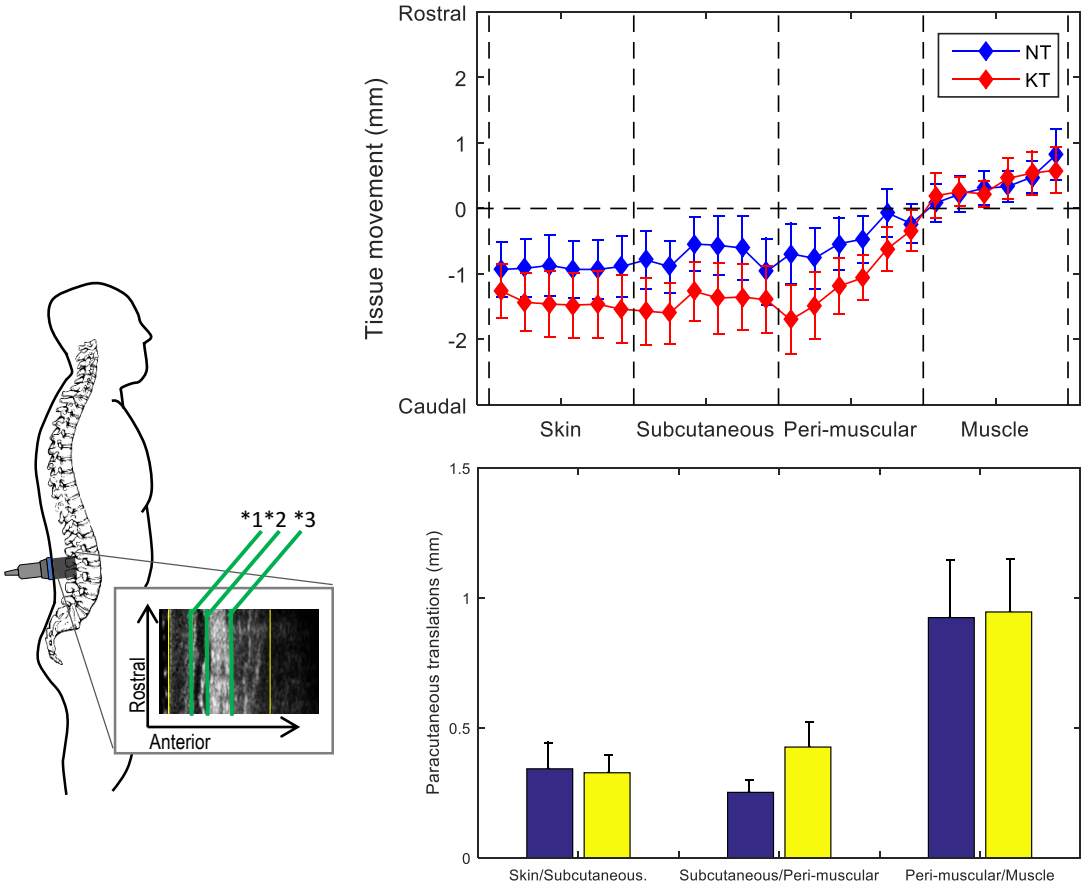


Figure 73. Comparison of para-cutaneous tissue translation before and after KT applied – in usual condition

Left: *demonstration of ultrasound scanning position, the orientation of the ultrasound image and the definition of boundaries between four tissue zones. *1: the boundary between skin and subcutaneous zones;*2: the boundary between subcutaneous and peri-muscular zones; *3: the boundary between peri-muscular and muscle zones.*

Top righ: *tissue movements in the sagittal plane are plotted n the y-axis and zones of the soft tissue on the x-axis (depth) during the retrun to neutral movement phase.*

Bottom right: *para-cutaneous tissue translation in the phase of return to neutral*

NT= No taping; KT= with Kinesio Taping.

Despite the trend that application of KT increased the inter-tissue para-cutaneous translation at all three tissue interface, there is no statistically significant difference was found when the subjects performed the usual neutral-to-flexion task. (p = 0.71 at the boundary between skin and subcutaneous zones; p = 0.22 at the boundary between subcutaneous and peri-muscular zones; p = 0.56 at the boundary between peri-muscular and muscle zones. Figure 73)

There was neither significant difference nor trend in changes of inter-tissue para-cutaneous translation after KT application during the return-to-neutral phases of standard movement task. (p = 0.90 at the boundary between skin and subcutaneous zones; p = 0.09 at the boundary between subcutaneous and peri-muscular zones; p = 0.93 at the boundary between peri-muscular and muscle zones. Figure 73)

Table 24. Descriptive statistic of data for all variables entered into the multivariate test – standard task flexion-to-neutral phase.

positive values in movements indicated KT increased movements toward the rostral direction, while negative values indicated KT increased movements toward caudal direction; positive values in para-cutaneous translations indicated KT increased tissue translation while negative values indicated reductions; Measurement unit: mm

Measure	LBP	Taping	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
M1	Asymptomatic	NT	-1.70	0.69	-3.12	-0.28
		KT	-1.16	0.61	-2.41	0.08
	LBP	NT	-0.91	0.67	-2.28	0.46
		KT	-1.44	0.59	-2.64	-0.24
M2	Asymptomatic	NT	-1.97	0.71	-3.42	-0.52
		KT	-1.49	0.56	-2.64	-0.34
	LBP	NT	-0.73	0.68	-2.13	0.68
		KT	-1.43	0.54	-2.54	-0.31
M3	Asymptomatic	NT	-1.29	0.57	-2.47	-0.12
		KT	-0.98	0.50	-2.00	0.03
	LBP	NT	-0.46	0.55	-1.59	0.67
		KT	-1.06	0.48	-2.05	-0.08
M4	Asymptomatic	NT	0.46	0.29	-0.14	1.05
		KT	0.96	0.30	0.35	1.58
	LBP	NT	0.37	0.28	-0.20	0.95
		KT	0.38	0.29	-0.22	0.97
P1	Asymptomatic	NT	0.41	0.11	0.18	0.64
		KT	0.29	0.07	0.14	0.43
	LBP	NT	0.34	0.11	0.12	0.56
		KT	0.33	0.07	0.19	0.47
P2	Asymptomatic	NT	0.40	0.08	0.24	0.56
		KT	0.44	0.12	0.20	0.68
	LBP	NT	0.25	0.08	0.10	0.40
		KT	0.43	0.11	0.20	0.66
P3	Asymptomatic	NT	0.95	0.22	0.51	1.40
		KT	1.12	0.22	0.68	1.57
	LBP	NT	0.92	0.21	0.49	1.35
		KT	0.95	0.21	0.51	1.38

M1 = skin movement; M2 = subcutaneous zone movement; M3 = fascial zone movement; M4 = muscle zone movement; P1 = para-cutaneous translation at interface between skin and subcutaneous zone; P2 = para-cutaneous translation at interface between subcutaneous and facial zone; P3 = para-cutaneous translation at interface between fascial and muscle zone. NT = no tape; KT = K-tape.

6.3.1.2 Seated lumbar flexion

Total tissue movements in the sagittal plane during the seated lumbar flexion task were plotted against normalised depths of the ultrasound image and tissue zones to compare the movement trend of tissues before and after KT (Figure 74). Descriptive statistics of all dependent variables were summarised in Table 25.

The neutral-to-flexion phase

There was no significant difference in the linear combination of all dependent variables (tissue movements in four zones and para-cutaneous translations at three interfaces) before and after receiving KT (Pillai's trace = 0.36, F (7, 8) = 0.63, p = 0.72). Follow-up separate univariate ANOVAs on the outcome variables revealed no significant difference in each ultrasound measurement variable before and after receiving KT.

There was no significant difference of inter-tissue para-cutaneous translation after KT application during the neutral-to-flexion phases of sitting lumbar flexion task. (p = 0.62 at the boundary between skin and subcutaneous zones; p = 0.72 at the boundary between subcutaneous and peri-muscular zones; p = 0.45 at the boundary between peri-muscular and muscle zones. Figure 75)

The return-to-neutral phase

There was no significant difference in the linear combination of all dependent variables (tissue movements in four zones and para-cutaneous translations at three interfaces) before and after receiving KT (Pillai's trace = 0.49, F (7, 8) = 1.09, p = 0.45). Follow-up separate univariate ANOVAs on the outcome variables revealed no significant difference in each ultrasound measurement variable before and after receiving KT.

Similarly, no significant difference of inter-tissue para-cutaneous translation after KT application during the return-to-neutral phases of this movement task was found. (p = 0.37 at the boundary between skin and subcutaneous zones; p = 0.45 at the boundary between subcutaneous and peri-muscular zones; p = 0.69 at the boundary between peri-muscular and muscle zones. Figure 75)

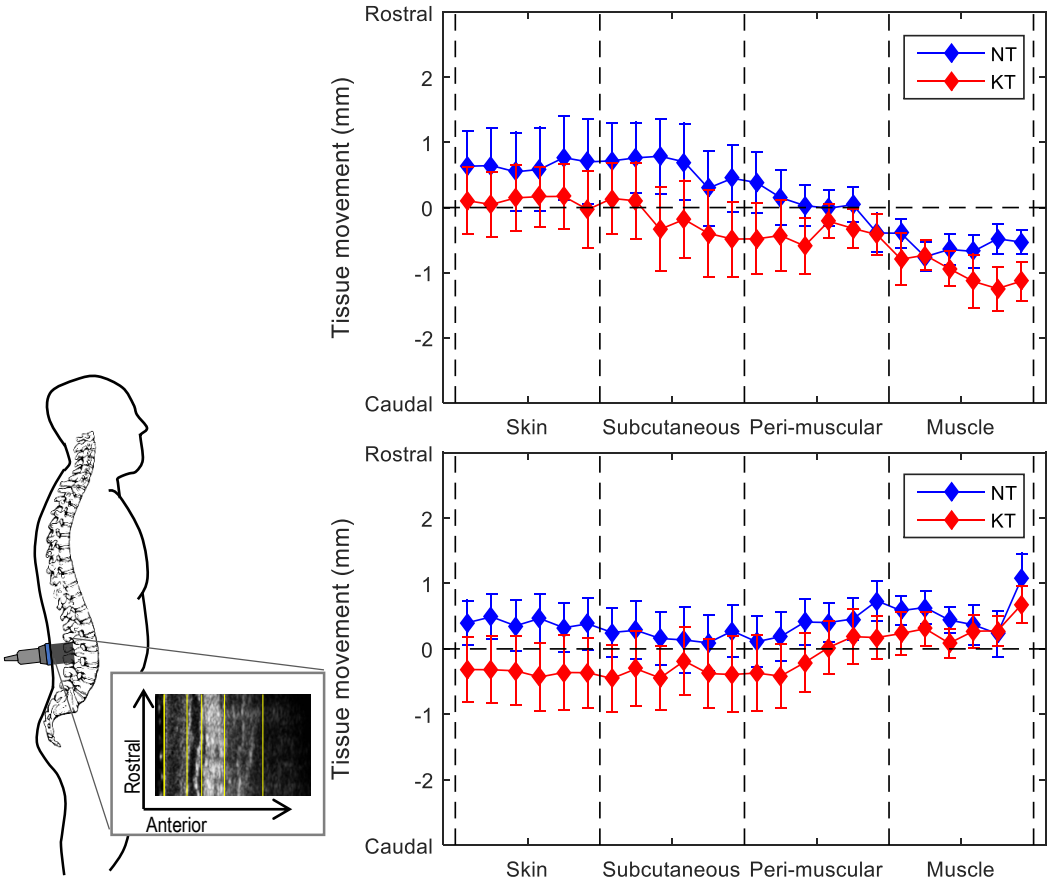


Figure 74. Comparison of tissue movements before and after KT applied – sitting on a stool

Left: *demonstration of ultrasound scanning position, the orientation of the ultrasound image and the location of four tissue zones.*

Top right: *tissue movements in sagittal plane against zones of the soft tissue (depth) in the phase of neutral to flexion.*

Bottom right: *tissue movements in sagittal plane against zones of the soft tissue (depth) in the phase of return to neutral.*

Table 25. Summary of tissue movements and para-cutaneous translation during the seated condition task.

positive values in movements indicated KT increased movements toward the rostral direction, while negative values indicated KT increased movements toward caudal direction; positive values in para-cutaneous translations indicated KT increased tissue translation while negative values indicated reductions; Measurement unit: mm

Phase	Measure	Taping	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Neutral-to-Flexion Phase	M1	NT	0.65	0.61	-0.65	1.95
		KT	0.10	0.51	-0.99	1.19
	M2	NT	0.62	0.55	-0.56	1.80
		KT	-0.19	0.59	-1.46	1.08
	M3	NT	0.04	0.32	-0.65	0.72
		KT	-0.41	0.38	-1.22	0.41
	M4	NT	-0.58	0.19	-1.00	-0.17
		KT	-1.00	0.28	-1.60	-0.39
	P1	NT	0.38	0.09	0.19	0.57
		KT	0.45	0.09	0.26	0.64
	P2	NT	0.53	0.10	0.31	0.75
		KT	0.49	0.10	0.27	0.70
	P3	NT	0.66	0.13	0.39	0.93
		KT	0.59	0.11	0.35	0.83
Flexion-to-Neutral Phase	M1	NT	0.40	0.36	-0.37	1.17
		KT	-0.35	0.52	-1.47	0.77
	M2	NT	0.20	0.41	-0.67	1.07
		KT	-0.36	0.53	-1.49	0.77
	M3	NT	0.38	0.31	-0.27	1.04
		KT	-0.10	0.44	-1.04	0.83
	M4	NT	0.56	0.25	0.03	1.09
		KT	0.31	0.21	-0.15	0.77
	P1	NT	0.41	0.11	0.18	0.63
		KT	0.29	0.06	0.16	0.42
	P2	NT	0.55	0.15	0.23	0.88
		KT	0.44	0.10	0.24	0.65
	P3	NT	0.50	0.11	0.26	0.74
		KT	0.58	0.14	0.28	0.88

M1 = skin movement; M2 = subcutaneous zone movement; M3 = fascial zone movement; M4 = muscle zone movement; P1 = para-cutaneous translation at interface between skin and subcutaneous zone; P2 = para-cutaneous translation at interface between subcutaneous and facial zone; P3 = para-cutaneous translation at interface between fascial and muscle zone. NT = no tape; KT = K-tape. (Measurement unit: mm)

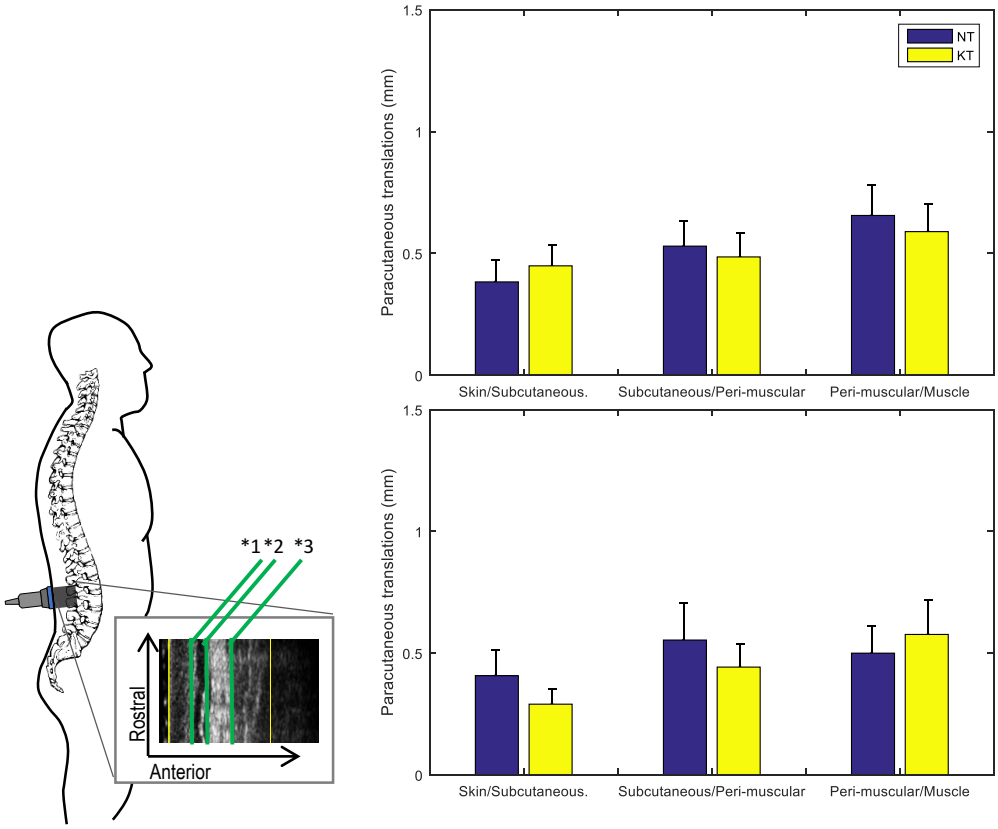


Figure 75. Comparison of para-cutaneous tissue translation before and after KT applied – in seated condition

Left: *demonstration of ultrasound scanning position, the orientation of the ultrasound image and the definition of boundaries between four tissue zones. *1: the boundary between skin and subcutaneous zones; *2: the boundary between subcutaneous and peri-muscular zones; *3: the boundary between peri-muscular and muscle zones.*

Top right: *para-cutaneous tissue translation in the phase of neutral to flexion.*

Bottom right: *para-cutaneous tissue translation in the phase of return to neutral*

NT= No taping; KT= with Kinesio Taping.

6.3.1.3 Lumbar flexion with extra load

Total tissue movements in the sagittal plane during the lumbar flexion task with extra load were plotted against normalised depths of the ultrasound image and tissue zones to compare the movement trend of tissues before and after KT (Figure 76). Descriptive statistics of all dependent variables are summarised in Table 26.

The neutral-to-flexion phase

There was no significant difference in the linear combination of all dependent variables (tissue movements in four zones and para-cutaneous translations at three interfaces) before and after receiving KT (Pillai's trace = 0.53, F (7, 8) = 1.27, p = 0.37). Follow-up separate univariate ANOVAs on the outcome variables also revealed no significant in the neutral-to-flexion phase.

The use of KT during the flexion phase of movement tasks performed with load resulted in no significant difference in inter-tissue translations at all three interfaces during the neutral-to-flexion phase. (p = 0.54 at the boundary between skin and subcutaneous zones; p = 0.46 at the boundary between subcutaneous and peri-muscular zones; p = 0.63 at the boundary between peri-muscular and muscle zones. Figure 77)

The return-to-neutral phase

There was no significant difference in the linear combination of all dependent variables (tissue movements in four zones and para-cutaneous translations at three interfaces) before and after receiving KT (Pillai's trace = 0.67, F (7, 8) = 2.36, p = 0.13). However, follow-up separate univariate ANOVAs on the outcome variables revealed a weak evidence suggesting that KT has reduced ultrasound based movement observation in the muscle zone by 0.44 mm after taping (F (1) = 4.28, p = 0.06).

There was no significant difference in para-cutaneous translation before and after KT during the return-to-neutral phase. (p = 0.78 at the boundary between skin and subcutaneous zones; p = 0.41 at the boundary between subcutaneous and peri-muscular zones; p = 0.52 at the boundary between peri-muscular and muscle zones. Figure 77)

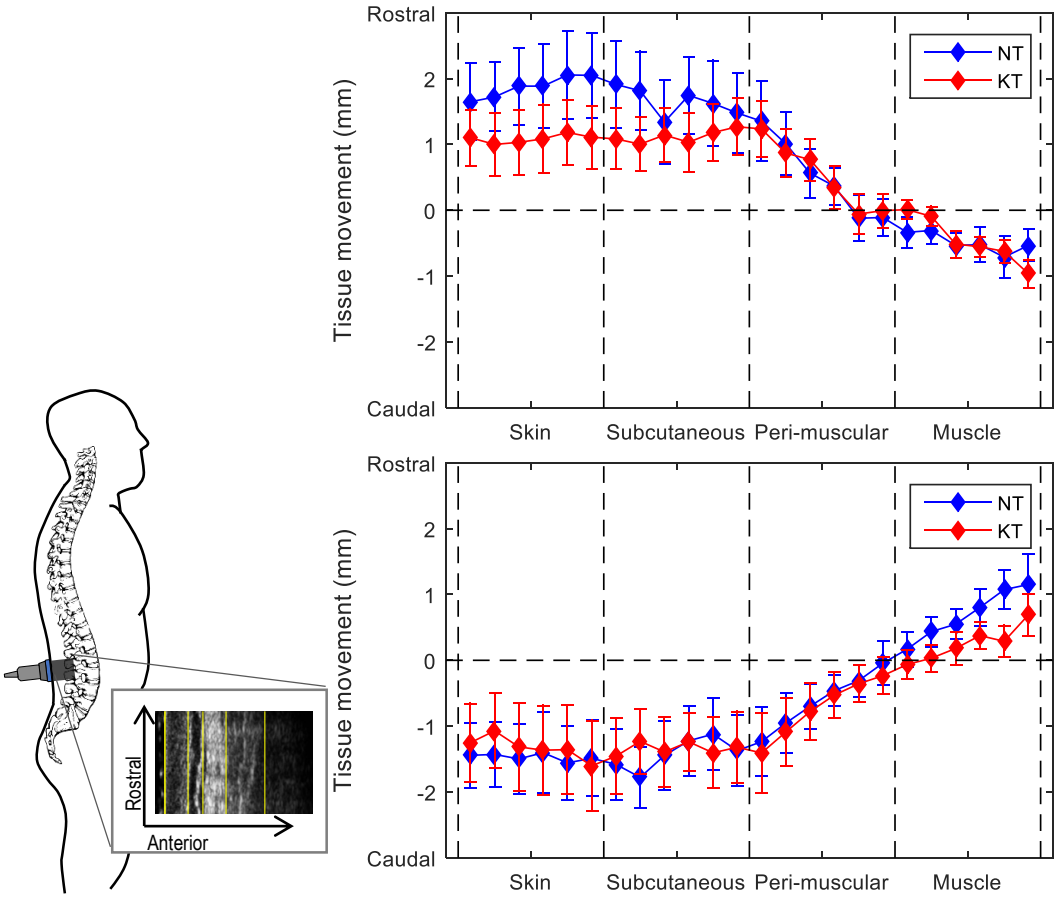


Figure 76. Comparison of tissue movements before and after KT applied – with extra load

Left: *demonstration of ultrasound scanning position, the orientation of the ultrasound image and the location of four tissue zones.*

Top right: *tissue movements in the sagittal plane are plotted n the y-axis and zones of the soft tissue on the x-axis (depth) during the neutral to flexion movement phase.*

Bottom right: *the same plot in the return-to-neutral phase.*

NT = no tape; KT = K-tape*.*

Table 26. Summary of tissue movements and para-cutaneous translation during the task with extra load

positive values in movements indicated KT increased movements toward the rostral direction, while negative values indicated KT increased movements toward caudal direction; positive values in para-cutaneous translations indicated KT increased tissue translation while negative values indicated reductions; Measurement unit: mm

Phase	Measure	Taping	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Neutral-to-Flexion Phase	M1	NT	1.87	0.60	0.59	3.16
		KT	1.09	0.48	0.06	2.11
	M2	NT	1.65	0.62	0.33	2.97
		KT	1.12	0.42	0.21	2.03
	M3	NT	0.51	0.34	-0.21	1.23
		KT	0.53	0.31	-0.14	1.19
	M4	NT	-0.49	0.20	-0.93	-0.06
		KT	-0.46	0.13	-0.73	-0.18
	P1	NT	0.41	0.12	0.15	0.67
		KT	0.34	0.05	0.22	0.45
	P2	NT	0.57	0.13	0.30	0.84
		KT	0.43	0.11	0.20	0.67
	P3	NT	0.65	0.14	0.35	0.96
		KT	0.75	0.13	0.47	1.03
Flexion-to-Neutral Phase	M1	NT	-1.47	0.54	-2.64	-0.31
		KT	-1.33	0.64	-2.70	0.05
	M2	NT	-1.42	0.51	-2.52	-0.32
		KT	-1.34	0.51	-2.44	-0.24
	M3	NT	-0.62	0.33	-1.31	0.08
		KT	-0.73	0.38	-1.55	0.08
	M4	NT	0.70	0.26	0.15	1.24
		KT	0.25	0.21	-0.19	0.69
	P1	NT	0.47	0.15	0.15	0.80
		KT	0.41	0.16	0.06	0.75
	P2	NT	0.45	0.08	0.28	0.62
		KT	0.34	0.11	0.10	0.58
	P3	NT	0.51	0.09	0.32	0.71
		KT	0.62	0.16	0.27	0.96

M1 = skin movement; M2 = subcutaneous zone movement; M3 = fascial zone movement; M4 = muscle zone movement; P1 = para-cutaneous translation at interface between skin and subcutaneous zone; P2 = para-cutaneous translation at interface between subcutaneous and facial zone; P3 = para-cutaneous translation at interface between fascial and muscle zone. NT = no tape; KT = K-tape. (Measurement unit: mm)

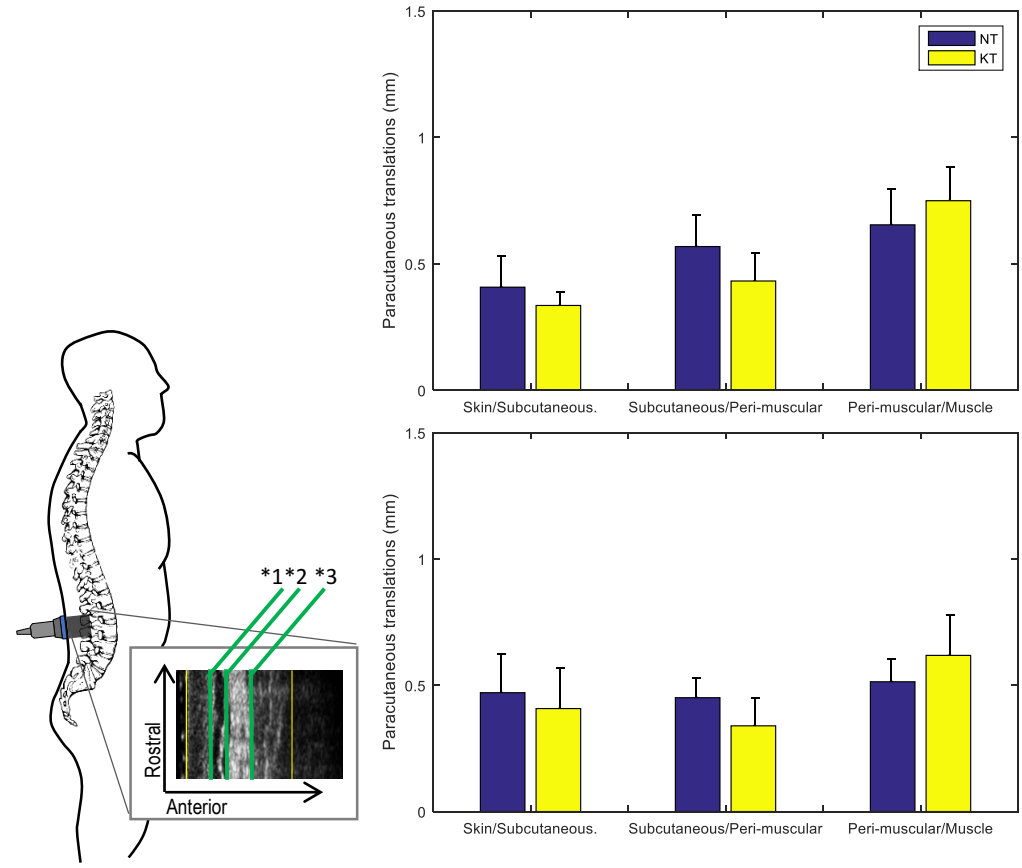


Figure 77. Comparison of para-cutaneous tissue translation before and after KT applied – with extra loads

Left: *demonstration of ultrasound scanning position, the orientation of the ultrasound image and the definition of boundaries between four tissue zones. *1: the boundary between skin and subcutaneous zones; *2: the boundary between subcutaneous and peri-muscular zones; *3: the boundary between peri-muscular and muscle zones.*

Top right: *para-cutaneous tissue translation in the phase of neutral to flexion.*

Bottom right: *para-cutaneous tissue translation in the phase of return to neutral*

NT= No taping; KT= with Kinesio Taping.

6.3.1.4 Lumbar flexion with support

Total tissue movements in the sagittal plane during the seated lumbar flexion task were plotted against normalised depths of the ultrasound image and tissue zones to compare the movement trend of tissues before and after KT (Figure 78). Descriptive statistics of all dependent variables were summarised in Table 27.

The neutral-to-flexion phase

There was no significant difference in the linear combination of all dependent variables (tissue movements in four zones and para-cutaneous translations at three interfaces) before and after receiving KT (Pillai's trace = 0.35, F (7, 8) = 0.62, p = 0.73). Follow-up separate univariate ANOVAs on the outcome variables revealed that no significant difference was found in the ultrasound data collected in the neutral-to-flexion phase.

There was no significant difference in the inter-tissue para-cutaneous translation between taping conditions at all three interfaces during the neutral-to-flexion phase of the upper body supported movement tasks. (p = 0.82 at the boundary between skin and subcutaneous zones; p = 0.35 at the boundary between subcutaneous and peri-muscular zones; p = 0.91 at the boundary between peri-muscular and muscle zones. Figure 79)

The return-to-neutral phase

There was no significant difference in the linear combination of all dependent variables (tissue movements in four zones and para-cutaneous translations at three interfaces) before and after receiving KT (Pillai's trace = 0.36, F (7, 8) = 1.98, p = 0.18).

Follow-up separate univariate ANOVAs on the outcome variables revealed that KT application did, however, result in a significant increase in the inter-tissue para-cutaneous translation at the interface between deeper fascia and muscle during the return-to-neutral phase of hand-supported movement tasks, with a mean increase of 0.34 mm after KT in the return-to-neutral phase (F (1) = 6.57, p = 0.02). There was no change in the inter-tissue para-cutaneous translation for any of the other interfaces during this phase. (p = 0.20 at the boundary between skin and subcutaneous zones; p = 0.99 at the boundary between subcutaneous and peri-muscular zones, Figure 79)

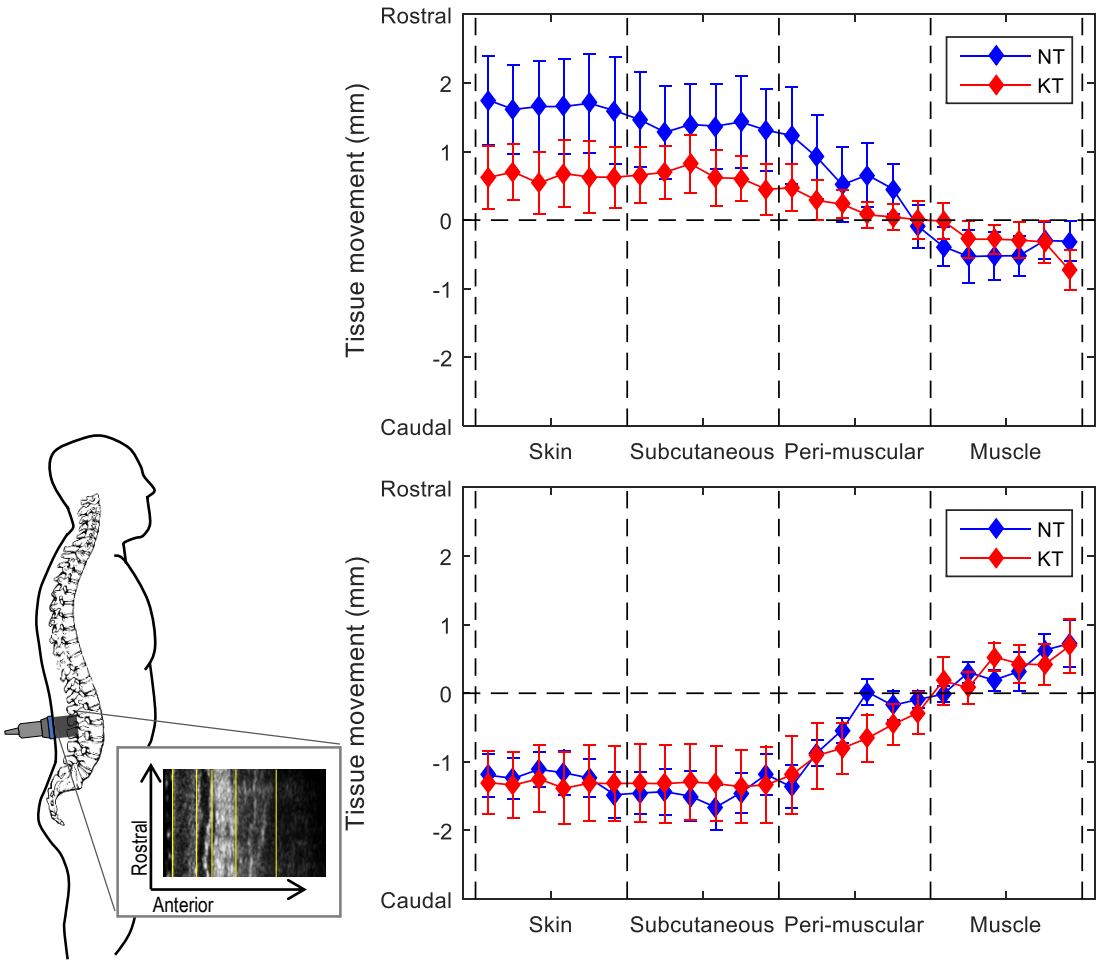


Figure 78. Comparison of tissue movements before and after KT applied – with support

Left: *demonstration of ultrasound scanning position, the orientation of the ultrasound image and the location of four tissue zones.*

Top right: *tissue movements in the sagittal plane are plotted n the y-axis and zones of the soft tissue on the x-axis (depth) during the neutral to flexion movement phase.*

Bottom right: *the same plot in the return-to-neutral phase.*

NT = no tape; KT = K-tape*.*

Table 27. Summary of tissue movements and para-cutaneous translation during the task with support.

positive values in movements indicated KT increased movements toward the rostral direction, while negative values indicated KT increased movements toward caudal direction; positive values in para-cutaneous translations indicated KT increased tissue translation while negative values indicated reductions; Measurement unit: mm

Phase	Measure	Taping	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Neutral-to-Flexion Phase	M1	NT	1.66	0.69	0.18	3.14
		KT	0.63	0.45	-0.34	1.61
	M2	NT	1.38	0.64	0.01	2.74
		KT	0.64	0.38	-0.17	1.45
	M3	NT	0.62	0.47	-0.39	1.62
		KT	0.19	0.18	-0.20	0.57
	M4	NT	-0.43	0.26	-0.98	0.13
		KT	-0.32	0.22	-0.78	0.15
	P1	NT	0.40	0.10	0.20	0.60
		KT	0.37	0.10	0.16	0.59
	P2	NT	0.46	0.10	0.24	0.68
		KT	0.35	0.10	0.12	0.57
	P3	NT	0.67	0.13	0.40	0.95
		KT	0.65	0.15	0.32	0.97
Flexion-to-Neutral Phase	M1	NT	-1.24	0.29	-1.85	-0.62
		KT	-1.32	0.51	-2.40	-0.23
	M2	NT	-1.45	0.30	-2.09	-0.81
		KT	-1.32	0.55	-2.50	-0.14
	M3	NT	-0.50	0.14	-0.81	-0.20
		KT	-0.72	0.36	-1.50	0.06
	M4	NT	0.36	0.17	0.01	0.71
		KT	0.39	0.26	-0.17	0.94
	P1	NT	0.26	0.09	0.07	0.45
		KT	0.17	0.05	0.07	0.27
	P2	NT	0.46	0.09	0.27	0.65
		KT	0.46	0.11	0.23	0.70
	P3	NT	0.40	0.09	0.22	0.59
		KT	0.75	0.13	0.47	1.02

M1 = skin movement; M2 = subcutaneous zone movement; M3 = fascial zone movement; M4 = muscle zone movement; P1 = para-cutaneous translation at interface between skin and subcutaneous zone; P2 = para-cutaneous translation at interface between subcutaneous and facial zone; P3 = para-cutaneous translation at interface between fascial and muscle zone. NT = no tape; KT = K-tape. (Measurement unit: mm)

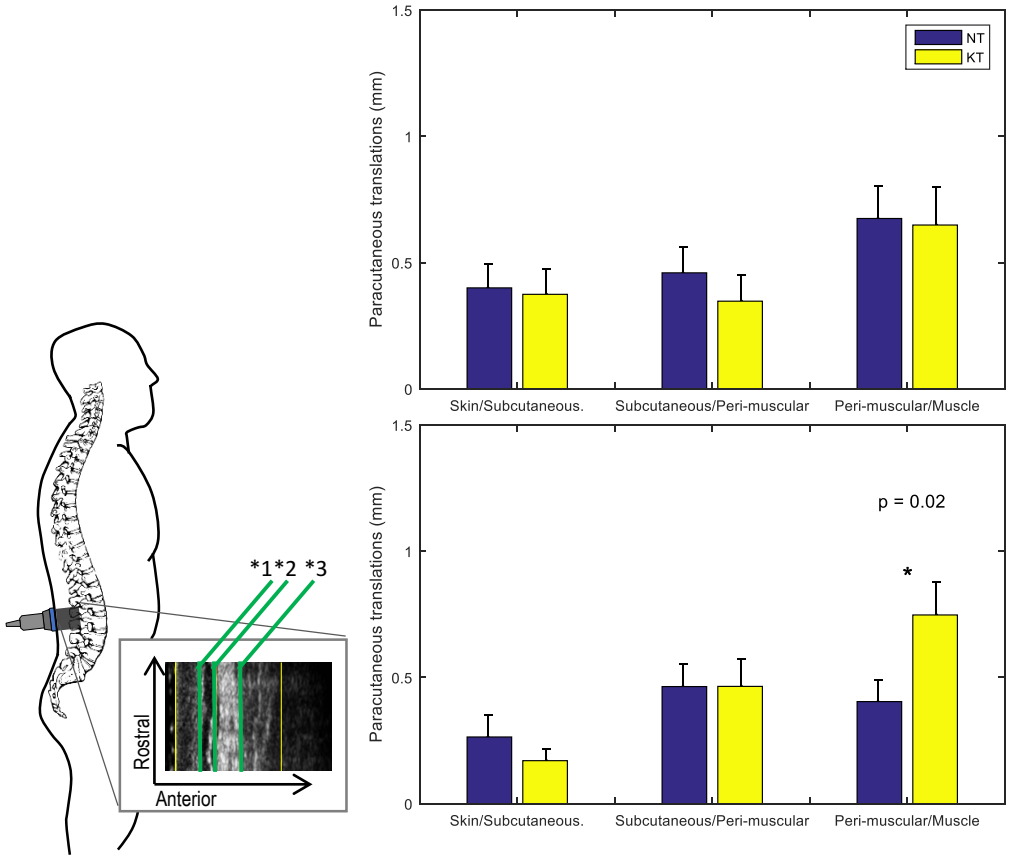


Figure 79. Comparison of para-cutaneous tissue translation before and after KT applied – with support

Left: *demonstration of ultrasound scanning position, the orientation of the ultrasound image and the definition of boundaries between four tissue zones. *1: the boundary between skin and subcutaneous zones; *2: the boundary between subcutaneous and peri-muscular zones; *3: the boundary between peri-muscular and muscle zones.*

Top right: *para-cutaneous tissue translation in the phase of neutral to flexion.*

Bottom right: *para-cutaneous tissue translation in the phase of return to neutral*

NT= No taping; KT= with Kinesio Taping.

6.3.2 Subgroup analysis

When looking at the neutral-to-flexion phase of movements, there is a significant difference on the linear combination of dependent variables, which include changes in soft tissue movements and para-cutaneous translations before and after receiving KT application, between responders and non-responders (Pillai's trace = 0.80, F (7, 7) = 3.93, $p < 0.05$). However, follow-up separate univariate ANOVAs showed no difference in individual variables between responders and non-responders. Detailed statistics were summarised in Table 28.

When looking at the return-to-neutral phase of movements, there was no difference in the linear combination of dependent variables after receiving KT application among responders and non-responders (Pillai's trace = 0.42, F (7, 7) = 0.71, p = 0.67). No difference in follow-up separate univariate ANOVAs was found, neither. Detailed statistics were summarised in Table 29.

Table 28. Comparison of soft tissue measurement difference before and after KT application between responders and non-responders: Neutral-to-flexion phase

positive values in movements indicated KT increased rostral movement, while negative values indicated KT increased caudal movements; positive values in para-cutaneous translations indicated KT increased tissue translation while negative values indicated reductions; Measurement unit was mm

				95% Confidence Interval		
Measure	**Sub-group**	**Mean**	**Std.Error**	**Lower Bound**	**Upper Bound**	**p-value**
M1	Non-Responders	1.05	1.53	-2.24	4.35	0.70
	Responders	2.01	1.87	-2.03	6.06	
M2	Non-Responders	0.89	1.55	-2.46	4.24	0.69
	Responders	1.88	1.90	-2.22	5.97	
M3	Non-Responders	0.45	0.92	-1.54	2.44	0.35
	Responders	1.88	1.13	-0.56	4.32	
M4	Non-Responders	-0.22	0.41	-1.09	0.66	0.64
	Responders	0.09	0.50	-0.99	1.16	
P1	Non-Responders	0.17	0.25	-0.37	0.70	0.55
	Responders	-0.07	0.30	-0.73	0.58	
P2	Non-Responders	0.50	0.37	-0.30	1.31	0.55
	Responders	0.14	0.46	-0.84	1.13	
P3	Non-Responders	0.15	0.32	-0.54	0.85	0.97
	Responders	0.13	0.40	-0.72	0.99	

M1 = skin movement; M2 = subcutaneous zone movement; M3 = fascial zone movement; M4 = muscle zone movement; P1 = para-cutaneous translation at interface between skin and subcutaneous zone; P2 = para-cutaneous translation at interface between subcutaneous and facial zone; P3 = para-cutaneous translation at interface between fascial and muscle zone. Non-Res. = non-responders

Table 29. Comparison of soft tissue measurement difference before and after KT application between responders and non-responders: Return-to-Neutral phase

positive values in movements indicated KT increased rostral movement, while negative values indicated KT increased caudal movements; positive values in para-cutaneous translations indicated KT increased tissue translation while negative values indicated reductions; Measurement unit was mm

				95% Confidence Interval		
Measure	**Sub-group**	**Mean**	**Std.Error**	**Lower Bound**	**Upper Bound**	**p-value**
M1	Non-Responders	-0.35	0.85	-2.18	1.48	0.75
	Responders	-0.79	1.04	-3.03	1.45	
M2	Non-Responders	-0.61	0.92	-2.60	1.39	0.88
	Responders	-0.84	1.13	-3.28	1.60	
M3	Non-Responders	-0.52	0.76	-2.17	1.13	0.87
	Responders	-0.73	0.94	-2.75	1.29	
M4	Non-Responders	-0.17	0.31	-0.84	0.51	0.41
	Responders	0.26	0.39	-0.58	1.09	
P1	Non-Responders	0.08	0.17	-0.28	0.45	0.37
	Responders	-0.16	0.21	-0.61	0.28	
P2	Non-Responders	0.27	0.12	0.01	0.53	0.24
	Responders	0.03	0.15	-0.28	0.35	
P3	Non-Responders	0.07	0.32	-0.63	0.77	0.81
	Responders	-0.06	0.40	-0.91	0.80	

M1 = skin movement; M2 = subcutaneous zone movement; M3 = fascial zone movement; M4 = muscle zone movement; P1 = para-cutaneous translation at interface between skin and subcutaneous zone; P2 = para-cutaneous translation at interface between subcutaneous and facial zone; P3 = para-cutaneous translation at interface between fascial and muscle zone. Non-Res. = non-responders

6.3.3 Range of motion

There were no significant differences in ROM between either taping conditions for any of the experimental movement tasks (Table 30).

Mean ROM during standard movement tasks without KT was 83.0 ± 15.6 degrees, versus 85.2 ± 19.8 degrees with KT applied (p = 0.58). The seated movement task found a mean ROM of 62.1 ± 12.5 degrees without KT applied, compared to 61.6 ± 13.1 degrees when KT was applied (p = 0.77). Mean ROM during the movement task with hand support was 72.5 ± 22.5 degrees without KT, versus 74.0 ± 20.3 degrees with KT (p = 0.52). Mean ROM during the movement tasks with load was 82.8 ± 11.8 degrees without KT, versus 84.5 ± 15.6 degrees with KT (p = 0.71).

Table 30. Table comparing ROM (degrees) with and without KT

Movement Task	**No tape**		**With KT**		**Improvement**		**p-value**
	Mean	SD	Mean	SD	Mean	SD	
Standard	83.0	15.6	85.2	19.8	2.3	11.6	0.58
Seated	62.1	12.50	61.6	13.1	-0.6	5.6	0.77
Hand Support	72.5	22.5	74.0	20.3	1.5	7.0	0.52
With Load	82.8	11.8	84.5	15.6	1.7	1.9	0.72

6.4 Discussion

The present study aimed to assess the effects of KT on the movements of the thoracolumbar tissue in people with LBP. This set of experiments explored evidence on actual mechanisms of KT to confirm whether the effect reported by previous publications may be mechanistically attributable to taping therapy rather than other factors. Soft tissue movement data were collected from participants with LBP while performing four designated experimental tasks, chosen to mimic everyday movements. The study results of chapter 5.1 revealed that the method of KT used reduces overall movements and tissue para-cutaneous translation between tissue layers, which may be considered as a potential therapeutic mechanism. By observing people with LBP performing the same or similar movement tasks, the investigator may confirm whether the changes reported in the last chapter are applicable to the treatment of LBP. Furthermore, dividing symptomatic participants into responders and non-responders may help us to understand pain mechanisms and soft tissue response characteristics. Based on this information, LBP treatments may be targeted in a better way.

6.4.1 Tissue movement and inter-tissue translation

The result of this study suggests that soft tissue in the thoracolumbar area move differently during experimental movement tasks in people with and without LBP. However, the effects of KT limiting tissue movements in specific tissue zone we have seen in asymptomatic volunteers become insignificant when combining with data collected from patients, and the Interaction of Taping and LBP had no effect on the difference in tissue movement between participants with and without pain. These results suggest that tissues in the thoracolumbar area move differently between LBP and asymptomatic participants in both tasks before and after receiving KT. These result corroborate the results of the study of Langevin et al. (2011), which suggested a 20% decrease in shear strain in the thoracolumbar fascia was predominant in chronic LBP patients, these findings challenged the theory that decreased shear predisposes individuals to develop chronic LBP, and that KT could be used to treat this. However, neither finding from this previous paper nor the present project imply causality. Such snapshot observations are not able to establish causal relationships between LBP and altered fascia characteristics. It could be that the reduction of shear strain is an adaptive change to reduce LBP during movement. Further research to help identify these factors is needed.

However, an important factor to note is that there was a trend towards an interaction between LBP presence and taping condition, albeit this underpowered analysis was not

statistically significant. A retrospective sample size calculation showed that at least 23 subjects would be required at 80% power for this relationship to be significant. Participants with LBP not only have different soft tissue characteristic before taping, but differ further after receiving KT. In order to present this difference, two sets of data were illustrated side by side for visual comparison (Figure 80). As it is clear that KT limited the tissue movements in the fascia zone in pain-free participants; while in the results of LBP subjects, KT increased the tissue movements in the same zone. Furthermore, the movement pattern of patients after taping seems to be similar to the movement pattern of pain-free participants before taping. These differences in the reaction may be washed out in the variables combination statistical test. Consequently, although the actions of KT on the subcutaneous tissues should not be ignored, statistical analysis does not yet provide strong evidence to demonstrate the beneficial effect of KT.

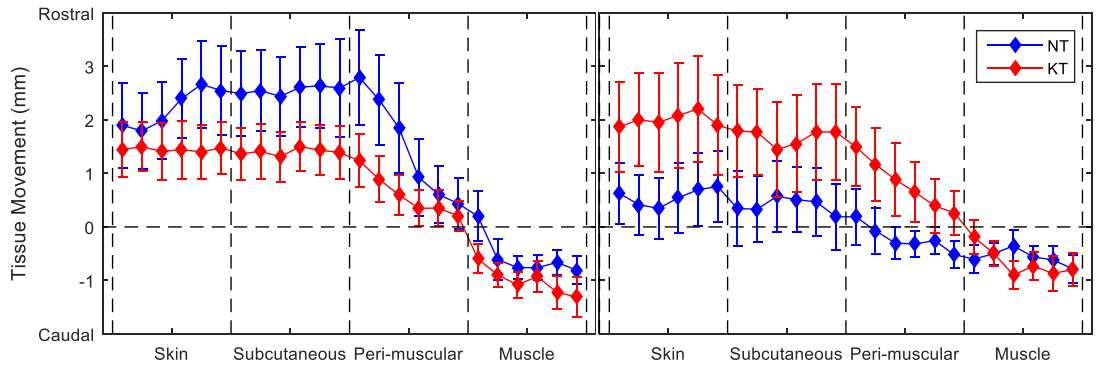


Figure 80. Comparison of tissue movements in sagittal plane against zones of the soft tissue (depth) in the phase of neutral to flexion between volunteers with and without LBP

Left: data collected from asymptomatic participants
Right: data collected from participants with LBP
NT= no taping (data in blue); KT= with KT (data in red); measuring unit= mm; error bars= standard error.

6.4.2 Potential sub-grouping

Since the data was able to demonstrate that people with LBP have different tissue responses to asymptomatic participants, it was judged worthwhile exploring whether there were any symptomatic subgroups who had different tissue reactions after the KT application. Participants who reported immediate pain reductions, up to 1.6 cm in VAS scale, after received the KT application were considered as responders. The result showed a significant difference in the linear combination of overall movements between responders and non-responders during the neutral-to-flexion phase. Although not significant due to large standard errors, increased tissue movements after the KT application were more obvious in the responders' subgroup (see Table 28 M1-M3). This statistical result was again

underpowered, due to the sample size reduction after subgrouping. Nevertheless, the result confirmed the possibility of the existence of subgroups. Future study is warranted, to help develop an identification tool to confirm which kind of patient may benefit from receiving KT application in early rehabilitation.

6.4.3 Range of motion

Similarly to the observational results reported in Chapter 5.1, this study found no evidence to suggest that the application of KT has an immediate effect on ROM. Similar results collected from asymptomatic participants have been reported (Lemos et al., 2014, Salvat and Salvat, 2010). Some factors about the variability of measuring ROM has been discussed in the last chapter. However, all the assessment method have been proven reliable before being used in these studies. We, therefore, should accept that KT had no effect on the lumbar ROM when LBP did not restrict ROM (or the 'no LBP' condition). Even though no effect on ROM can be confirmed, a mean $2.3 \pm 11.6°$ has been reported in the present chapter. This means some people may *feel* it is easier to move after taping, which may be a reason to explain the popularity of KT. However, monitoring ROM was not the primary aim nor objective of this study. It should be noted that the absence of changes in whole body ROM means that all tissue movements observed with ultrasound were produced in the same range of trunk movements.

6.4.4 Limitations

There were several limitations to this study. Firstly, unlike Chapter 5.2 the effects of sham taping had not been considered in the procedure; this did, however, simplify the data collection process and provided a more focused view of findings. Secondly, in order to effectively capture ultrasound images over the taped area, a small part of the strip had to be removed from the KT, as ultrasonic waves do not penetrate KT. This could have reduced the actions of KT. Although this could have been avoided by changing the angle of ultrasound beam during scanning, cutting a window on the tape provided a better control of ultrasound probe, which is essential for achieving the adequate quality of ultrasound images. It was however ensured that each window was cut identically in a relative position for all participants so that effects were consistent throughout the study.

Another limitation was the fact that the ultrasound could only assess a portion of the thoracolumbar fascia due to the size of the ultrasound probe. Movements of the entire thoracolumbar fascia could therefore not be assessed; the level assessed (second and third

lumbar vertebrae) did, however, provide a flat surface for the probe to be placed, allowing the retrieval of the highest quality images.

6.4.5 Implications and future approaches

Regardless of these limitations, this study was able to demonstrate some direction of effect and mechanism of KT. First of all, it was found that the application of KT results in no significant immediate improvement in ROM in both participants with and without non-specific LBP. The effects of prolonged KT use on these outcome measures could, however, merit further investigation. Secondly, this study was able to demonstrate that the application of KT can somewhat alter soft tissue dynamics, with weak evidence, which is due to small sample size and natural variance of tissue movements, although not in all the assessments. The effect on these tissues does, however, vary depending on the phase of movement (flexion or extension) and type of movement (standard, seated, with support or with load) being performed; as well as the condition of back pain of the participant. Further research into the nature of soft tissue dynamics during different movements would, therefore, strengthen the results of this study.

6.5 Chapter summary

Ultrasound-based soft tissue movement measurements were made during lumbar flexion tasks in four conditions – usual, seated, with extra load and reduced load. The results suggest that KT did not change ROM or tissue dynamics during these tasks. However, the result also suggests that people with LBP react to KT differently in comparison with asymptomatic volunteers. Further subgroup exploration indicated that people who reported immediate pain relief after KT have different soft tissue responses from those who did not benefit from KT application.

CHAPTER 7 DISCUSSION AND CONCLUSION

7.1 From motivation to clinical implications

7.1.1 Motivation and thesis focus

The initial motivation for conducting this project was to explore whether KT is an effective treatment and how it might work in achieving any observed effects on the human body. Figure 81 shows the initial project developments. A wide-ranging narrative review and an LBP focussed systematic review were completed to explore current evidence on the effects and mechanisms of KT and therefore inform study direction and thesis focus.

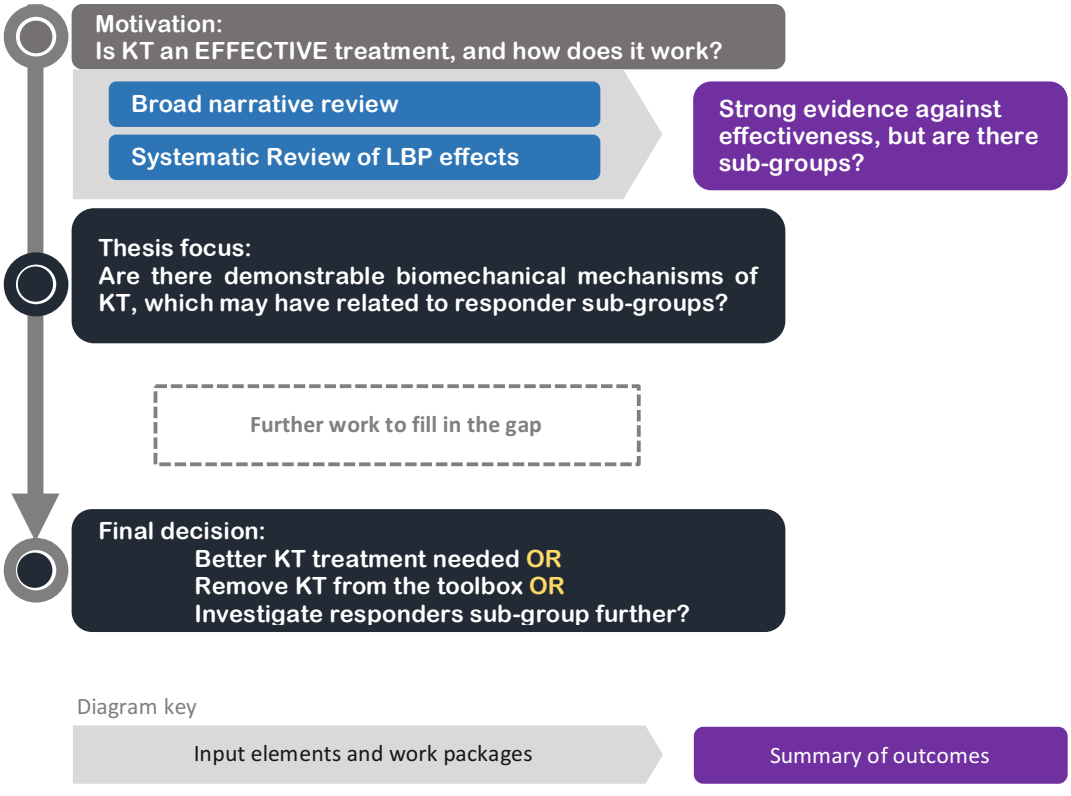


Figure 81. Demonstrates the initial flow of project design and literature review outcomes.
Diagram keys: within each step of the flow, the grey shaded area *on the left contains work packages and input elements; the purple rectangle on the right contains outcomes of the described stage.*

The broad ranging literature review (Chapter 1) about the effects and mechanisms of KT in musculoskeletal treatments demonstrated that KT may have small effects for particular treatment purposes such as pain relief, however the effect was typically rather trivial. For example, Castro-Sánchez et al. (2012) reported a mean difference of 1.1 (95% CI = 0.3 - 1.9) points in VAS scale between KT and shame taping in treatment of LBP. The difference was too small to be clinical important despite its significance. Previous systematic reviews evaluated a broad range of KT effects on selected outcomes. These approaches were across areas including the effectiveness for the prevention and treatment of sports injuries (Williams et al., 2012); for treatment of musculoskeletal conditions in general (Mostafavifar et al., 2012); for treatment of neurological and lymphatic conditions (Kalron and Bar-Sela, 2013, Morris et al., 2013). The other two reviews compared the effect of KT with other forms of interventions, by reviewing randomised controlled trials, which include patellofemoral pain, LBP, neck pain, sub-acromial impingement, rotator cuff tendonitis, and plantar fasciitis (Parreira et al., 2014a, Lim and Tay, 2015). Including a broader range of materials allowed a wider overview when examining the effects of KT. Despite having slightly different focus, all the reviews above have a similar conclusion that KT may have a small beneficial effect on targeted clinical measurements, but current evidence was insufficient for or against KT applications in these patient groups. Therefore, health professionals require further high-quality evidence to confirm if KT treatment is a worthwhile tool or a fashion.

The danger of looking at a range of systematic reviews was that the message would suffer from regression to the mean, as each condition has its own pathological mechanism and may be treated differently even with the same tool. Negative results in one area might be offset by positive results for another – with any useful clinical or mechanistic information being lost as a result. A focused review was therefore deemed necessary to carefully examine the effects of KT on LBP care.

The focused systematic review examining KT effects on LBP (Chapter 3) determined that KT does not appear to provide significant clinical pain relief when compared to other treatment modalities. Comparison between treatment including KT and usual care at reducing disability is currently conflicting due to different outcome indices (RMDQ, ODI and QBDS) being used in previous studies. Having the same concern as stated above, greater homogeneity is needed between future studies to facilitate evidence synthesis and therefore these results should be considered with caution, in particular the use of analgesics, taping technique and sham therapy applied (in reflection of Aim and Objective 1, pp.11). A review published soon after completion of my review had comparable findings to my own (Nelson, 2016).

Study heterogeneity notwithstanding, the outcomes of the two literature review approaches yielded the result that treatment including KT or KT application on its own were not better than usual care – a finding in direct contrast with the observed popularity. However, some immediate effects, such as effects of KT on acute non-specific LBP reported by Kelle et al. (2016), were difficult to ignore, because this high-quality trial revealed that patients with LBP being treated with KT consumed less paracetamol (2.35(0.84) tablets less on day one to four and 2.09(0.84) tablets less on day five to eight). These result shows that KT may be useful in acute LBP.

Based on these preliminary literature surveys and judgements, KT seems to be useful but not consistently. Were there any missing parts of the puzzle? Before making progress towards a final recommendation of rejecting KT on the grounds of observed minimal efficacy, I needed to switch focus to clarifying the mechanisms of KT and to explore sub-groups of people with LBP who respond to treatment differently. The aim of this thesis switched from examining effectiveness to determining whether biomechanical tissue responses could be identified and then used to determine sub-groups of responders or non-responders to KT. As presented in Figure 81, the primary goal of this thesis was to decide whether keeping KT in the clinical toolbox and research focus of LBP care was worthwhile. If confirmed, how might better treatments with KT be delivered?

7.1.2 Methodological development outcomes

Robust methods are required to achieve the aim of mechanism exploration with Figure 82 showing the methodological development as an additional step of my study journey. A three-dimensional ultrasound tissue movement tracking method was developed. The second soft-tissue assessment method – ultrasound elastography – was sourced through collaboration, and both tools were used to examine the effect of KT on the soft-tissues; movement and stiffness respectively.

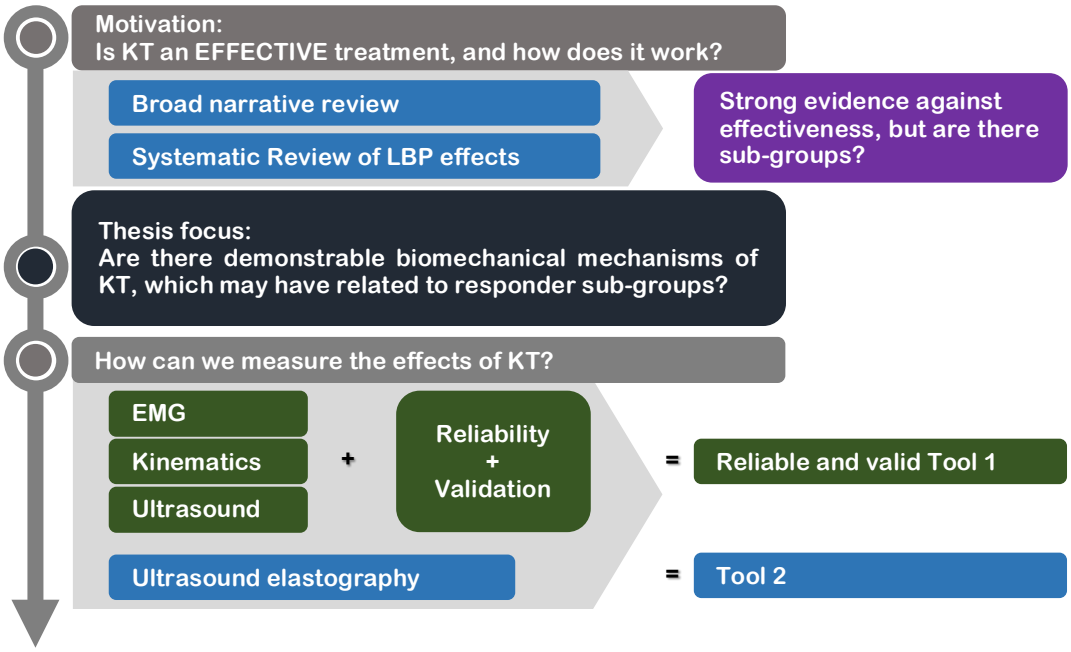


Figure 82. Demonstrates the additional step – methodological development work.

At this stage, available measurement tools in the Human Performance Lab were used in the developmental process. After initial testing on the phantoms and human subjects, the outcome is a reliable soft tissue movement monitoring tool.

Diagram keys: within each step of the flow, the grey shaded area *on the left contains work packages and input elements; the purple rectangle on the right contains outcomes of that stage.*

7.1.2.1 Semi-automatic ultrasound based tissue movement tracking method

Ultrasound is a reliable tool for quantification of abdominal and trunk muscle features with low levels of measurement error (Hebert et al., 2009). Ultrasound has also been used in the evaluation of fascia, such as plantar fascia (Karabay et al., 2007) and thoracolumbar fascia (Bishop et al., 2016, Langevin et al., 2011, Langevin et al., 2009). With higher sampling frequency and resolution, b-mode ultrasound was also used in some dynamic detections, for example, muscle fibre (Miyoshi et al., 2009) and nerve (Dilley et al., 2001) movements. However, there is no standard method for assessment of soft tissue movement due to the variety of image features, for example, Langevin et al. (2009) reported altered connective tissue structures in people with LBP. This increased the complexity when attempting to develop a universal auto-detection method for soft tissue dynamics.

A semi-automatic ultrasound based tissue movement tracking method was developed using motion capture and clinical b-mode ultrasound (Chapter 4). The development included clinical imaging learning and phantom-based training as the ultrasound image accuracy is strongly correlated with examiner experience (Hebert et al., 2009). Apart from clinical training, the development of an image processing algorithm played a critical role in methodological development. Three prior tests were performed in order to ensure the

reliability and validity of the semi-automatic movement detection algorithm. The result of repeatability showed that the semi-automatic movement detection method was sufficient for evaluations of soft-tissue in the thoracolumbar area of human subjects, with an ICC of 0.82, based on the classifications by Cicchetti (1994) and Lohr et al. (1996) (in reflection of Aim and Objective 2, pp.18)

The results of gelatine phantom testing indicated no systematic difference between proprietary ultrasound machine measurements and external calliper measurements, with an excellent interclass correlation coefficient of 0.99. The result of final validation test, which was performed using a fresh meat phantom, indicated that the developed soft tissue assessment procedure is able to accurately detect slow movements. No systematic difference was found between semi-automatic algorithm outputs and kinematic marker measurements, and the interclass correlation coefficient indicated that the algorithm was again sufficiently accurate. Chen et al. (2011) reported a similar level of reported a similar level of repeatability and validity results (inter-observer ICC = 0.98, validity ICC = 0.76 – 0.94) on their ultrasound-based method of the spinal deformity assessment. The development of ultrasound assessment methods in the present project was considered good enough to detect difference in the present project.

Soft tissue deformations during movements can be a potential limitation of ultrasound-based tissue assessment method. Herbert et al. (2002) demonstrated that only 55(13) % of specific muscle fascicles changed can be observed during contraction. Similarly, the software developed in the present project is able to detect tissue deformations only when the deformed portion of the tissue was totally included the observation window. However, the size of the ultrasound probe view is always a limitation of ultrasound-based studies. The assessment could only be performed at limited positions of the whole tissue. To minimise this concern, the scanning position was carefully chosen (at the second and third level of lumbar spine) following previous study (Langevin et al., 2009). Sub-cutaneous tissues are almost parallel to the skin surface at this level, and the relatively flat surface at this level ensure the retrieval of higher quality images. These improve the accuracy of automatic movement detection (Langevin et al., 2011, Langevin et al., 2009).

The primary objective of this method development (Aim and Objective 2, pp.18) was to design a method for the automatic detection of soft tissue movements via a cine ultrasound images. The results demonstrated that the developed image retrieval method and analysis algorithm could quantify the movement distance with sufficient repeatability. In comparison

with manual feature recognition and data handling, this development made it possible to process a large amount of data in an acceptable amount of time, and ultimately to examine KT mechanisms.

7.1.2.2 Ultrasound elastography

Apart from developing an innovative method to discover the mechanism of KT, ultrasound shear wave elastography was considered, which is a relatively newly developed technique quantifies the shear elastic modulus of a localised area of tissue (Bercoff et al., 2004, Shinohara et al., 2010). A linear relation between muscle shear elastic modulus and muscle stress during passive stretching has been reported (Chernak et al., 2013, Koo et al., 2013, Maïsetti et al., 2012). This technique is, therefore, used in assessment of tendon (De Zordo et al., 2009, Turan et al., 2013), ligament (Wu et al., 2015), muscle (Lacourpaille et al., 2012, Maïsetti et al., 2012, Shinohara et al., 2010) and fascia (Luomala et al., 2014). It has also been shown that ultrasound shear wave elastography provides a reliable measure of tissue elastic modulus (Lacourpaille et al., 2012). This technique, therefore, provides a unique opportunity to quantify the effect of taping on tissue stiffness.

Even though ultrasound elastography provides a quantitative analysis of tissue stiffness with low variability and measurement bias (Franchi-Abella et al., 2013), there were a few limitations using this technique. The major concern is that the data output has to rely on the processing algorithms provided by the manufacturer for producing and displaying elastographic images. Therefore, the findings and the artefacts may be highly dependent on this 'black box'. The elastography machine, which was mentioned in Chapter 5-2, was designed to evaluate shear wave velocity using a 1 Hz pulse signal. This, therefore, eliminated the possibility of collecting data while participants performed dynamic lumbar movements. Instead of performing the preferred lumbar flexion task, participants were asked to adopt three lumbar postures during the experiment. The alternative setting also ensures the control of ultrasound probe pressure and ultrasound beam, which are more sensitive parameters to elastography.

7.1.3 Initial observation outcomes

Having two assessment methods available, Figure 83 shows the initial observation works on asymptomatic participants as the first step filling the gap. Two studies (Chapter 5) were conducted to examine the effect of KT on soft tissue biomechanics, and the outcome was summarised in the box on the right side.

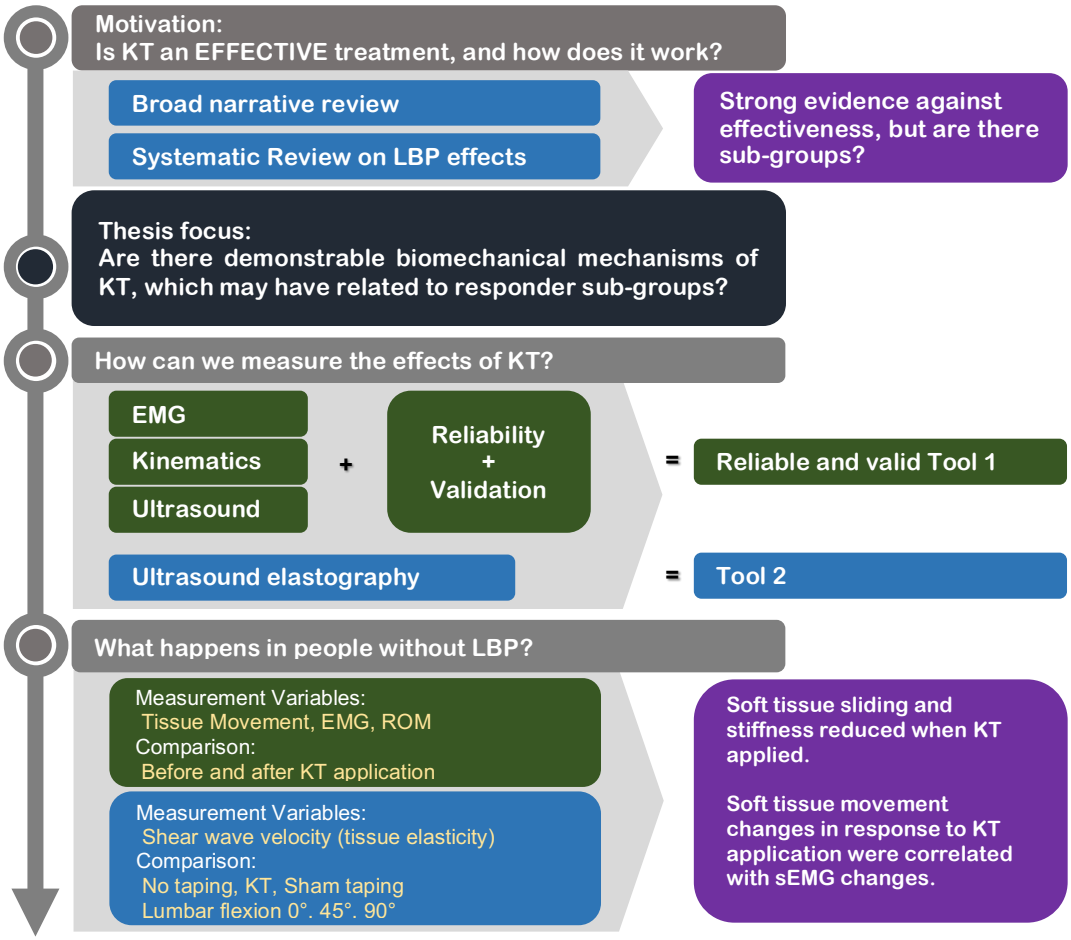


Figure 83. Demonstrates the additional step – observational work in people without LBP.

At this stage, two measurement tools were used to evaluate tissue dynamic and property before and after KT was applied to asymptomatic participants.

Diagram keys: within each step of the flow, the grey shaded area *on the left contains work packages and input elements; the purple rectangle on the right contains outcomes of the stage.*

7.1.3.1 Tissue movement and tissue elasticity changes

The result of initial test re-test observation shows that KT limited tissue movements in the subcutaneous zone, which is the area that contains fatty tissue and superficial fascia, during the neutral-to-flexion phase when the subjects were performing lumbar flexion tasks. However, KT did not repeat the alterations in the return-to-natural phase when the subjects were performing the same tasks. Interestingly, even though the tissue movements were moderated by KT, the mean angle of lumbar flexions was slightly increased after taping, although the result of ROM change was not statistically significant. The other interesting finding of this observation was that KT reduced para-cutaneous tissue translation between tissue layers, which is usually described as gliding, or strain in other studies. The rationale for using this terminology (para-cutaneous) has been stated in Chapter 4.5.2.1.2. These results suggest that KT is likely to change the actions of the connective tissue, and this change may be considered as a primary mechanism of KT applications (in reflection of Aim and Objective

3, pp.19). However, these findings may conflict with the findings published by Langevin et al. (2011) which suggested a 20% decrease in relative movement (reported as shear strain) between skin and muscle during passive lumbar flexion and a subsequent reduction in deformation of the TLF predominant in people with history of chronic LBP. It is very difficult to clarify whether LBP is casual about this alteration. In other words, we do not know if the reduction in tissue deformation Langevin found in LBP patients is a cause of pain or a beneficial, protective, movement change. Likewise, it remains unclear whether the observed reduction by KT in tissue movement and deformation of the fascia, which is similar to the reduction which Langevin found in patients, is beneficial. The thicker and altered structure of thoracolumbar fascia in patients with LBP reported by Langevin et al. (2009) can be considered as the fundamental mechanism of these biomechanics changes. However, other tissue biomechanical properties, such as tissue elasticity, are a potential measurement approach to complete the theory.

Taping is potentially able to alter soft tissue stiffness, Hug et al. (2014) reported that thigh muscle shear elasticity at rest and during contraction was affected by a specific taping technique using rigid tape. Although a different tape type and technique was used in this study, these findings indicated that biomechanical properties of deep tissues can be altered by introducing superficial tension, such as taping. The aim of my second observational study (Chapter 5.2) was to assess associations between KT treatment and tissue stiffness and to explain the tissue movement mechanisms demonstrated in Chapter 5.1.

The key finding in tissue elasticity observation was that a significant interaction between lumbar posture and taping on shear wave velocity was found in the two-factor ANOVA. This implies that KT applications changed the correlation between fascia stiffness and lumbar posture. Follow up posthoc tests confirmed this change, with a trend towards reduced shear wave velocity across the thoracolumbar fascia being identified, and a significant reduction in stiffness at 90° of lumbar flexion in both the subcutaneous zone and the deep fascial zone, with KT applied (in reflection of Aim and Objective 4, pp.19). Sham taping, conversely, showed no differences from no taping, but a significant increase in shear wave velocity at 90° of flexion in comparison with KT. These results suggest that KT seems to be able to alter tissue biomechanics in a specific position when the participants adopted a particular posture. Moreover, KT needs to be applied in a certain way to achieve desired result. This can be considered as an association with the classic theories that state structural compressions on the spine are positively correlated with flexion positions (Nachemson, 1981, Wilke et al., 1999). The effect of KT presented when participants adopt to a most uncomfortable position.

7.1.3.2 Tissue movements and muscle activations

Apart from soft tissue biomechanics, muscle activity was analysed to confirm if tissue movement changes were explained by muscle activity changes due to the fact that previous studies note altered muscle activities when KT was applied to other portions of the body (Gómez-Soriano et al., 2014, Martínez-Gramage et al., 2016). Neuromuscular control and recruitment patterns of muscles during trunk movements control have been shown to be associated with chronic LBP (Jacobson, 2009, MacDonald et al., 2009). Impaired neuromuscular control and muscle contraction may be another cause of the reduction of para-cutaneous soft tissue translations. The aim of collecting EMG data during lumbar movements was therefore to discover the neuromuscular mechanism of KT.

Although electromyography changes after KT application within single channels were not significant, the across channel analysis showed significant difference in EMG amplitude and frequency during the eccentric phase of lumbar flexion. Additionally, the muscle activation changes were positively correlated with the tissue movement changes, explaining 22% of the variance. This means integral of EMG increased or decreased did not correspond with the overall tissue movement (summary of all tissue zones). Although lower statistical power caused by analysing multiple variables at the same time is a concern, the data indicated a possible mechanism of KT. Changes in EMG showed that different types of motor unite may be recruited after receiving taping stimulation via subcutaneous soft tissues (in reflection of Aim and Objective 3, on page 19).

7.1.4 Symptomatic observational study outcomes

Since the initial observational results indicated that KT may alter soft tissue biomechanics in participants without LBP, the next focus was to investigate how KT works in symptomatic participants. Symptomatic participants were evaluated using the ultrasound-based assessment method developed in the Human Performance Laboratory (Chapter 6). The primary objective in this stage was to compare the tissue response of symptomatic participants with asymptomatic participants. The secondary objective was to investigate if KT changed soft tissue biomechanics under different conditions, such as changing loads or postures. By combining the outcomes of two objectives, an interim outcome was drawn and the potential for sub-group definition identified (Figure 84).

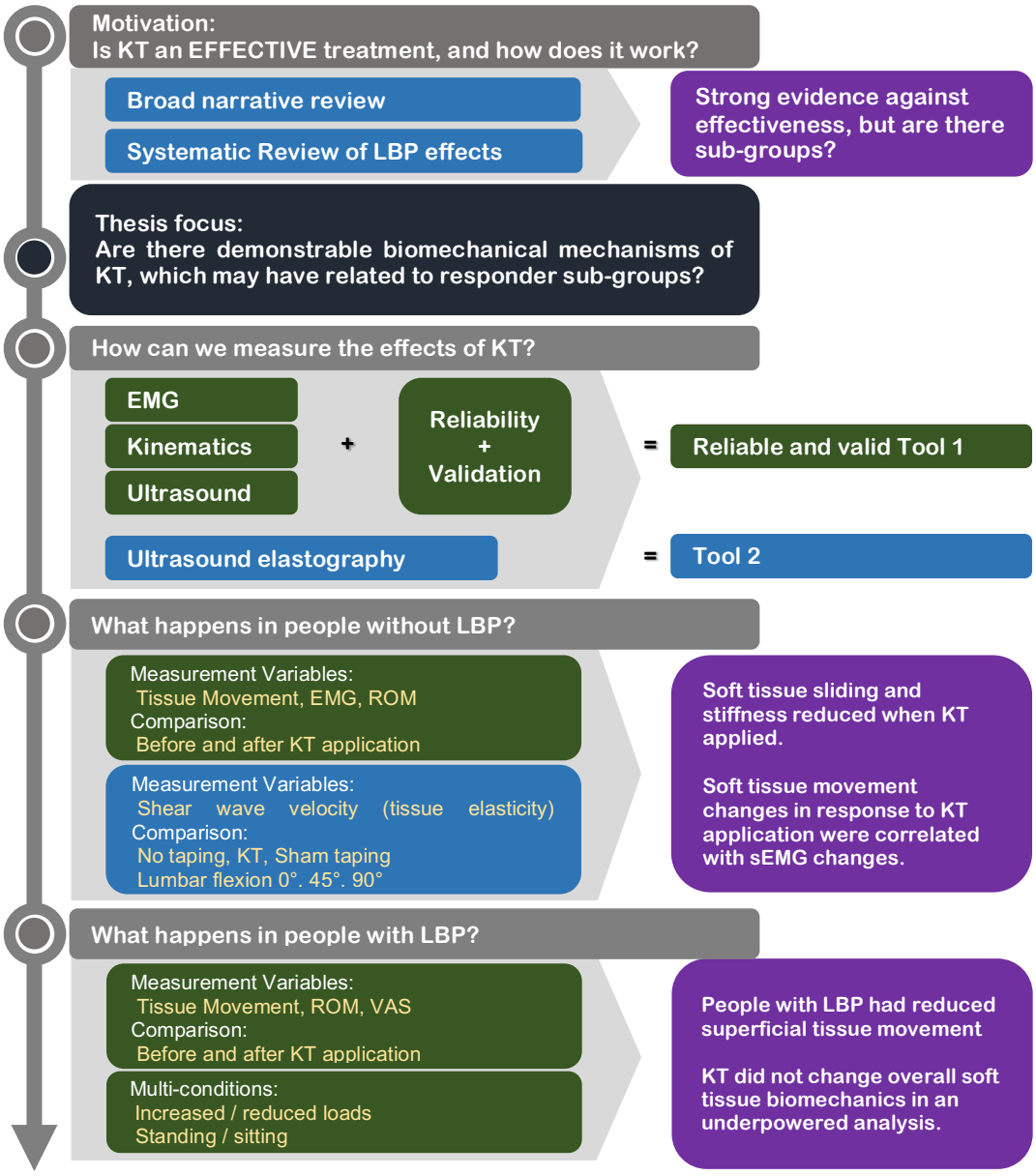


Figure 84. Demonstrates the additional step – observational work in people with LBP.

At this stage, prior developed measurement methods were used to evaluate tissue dynamic before and after KT was applied to symptomatic participants.

Diagram keys: within each step of the flow, The grey shaded area *on the left contains work packages and input elements; the purple rectangle on the right contains outcomes of the stage.*

7.1.4.1 Asymptomatic versus LBP, before and after taping

The results of observations in people with LBP suggest that thoracolumbar tissue moved differently during the experimental movement task in comparison with asymptomatic participants (in reflection of Aim and Objective 5, pp.19). This finding corresponded with the results of a previous study which reported people with LBP have a significant reduction in thoracolumbar fascia deformation during passive lumbar flexion when compared to asymptomatic controls (Langevin et al., 2011). However, the two-factor MANOVA was not able to demonstrate a significant difference in tissue movements before and after participants received KT applications (in reflection of Aim and Objective 5, pp.19). Figure ***85*** illustrates the two-factor comparison of the tissue movement between asymptomatic and LBP participants and between performing lumbar flexion with no taping and with KT. Even though the interaction between factors (group x taping) was not significant in the multivariate test, a trend towards diffident ways of reacting to KT in people with and without LBP was distinguishable. Tissue movement patterns before and after KT application in asymptomatic and LBP groups were plotted in Figure ***85*** to verify how people with and without pain reacted to KT. KT reduced soft tissue movements in asymptomatic participants while, increased tissue movements in LBP participants, particularly in sub-cutaneous and peri-muscular zones, which were considered as connective tissues. The follow-up univariate test demonstrated weak evidence to confirm this underpowered interaction. Despite no difference being found in muscle zone, these results suggest that tissues in the thoracolumbar area not only move differently between LBP and asymptomatic participants in both tasks but that the soft tissue also responds differently when receiving KT.

It is interesting to note that the movement patterns with KT application in both groups were almost identical in the sub-cutaneous and peri-muscular zones. This could be the potential mechanism of how KT delivers its effect by changing tissue biomechanics, although the tissue movement pattern after taping in LBP group was similar to the pattern after taping in the asymptomatic group rather than before taping. Including more information is therefore needed to move forward towards the final decision-making process. For example, sub-group LBP participants by the pain relief effect, and compare their dynamic tissue response.

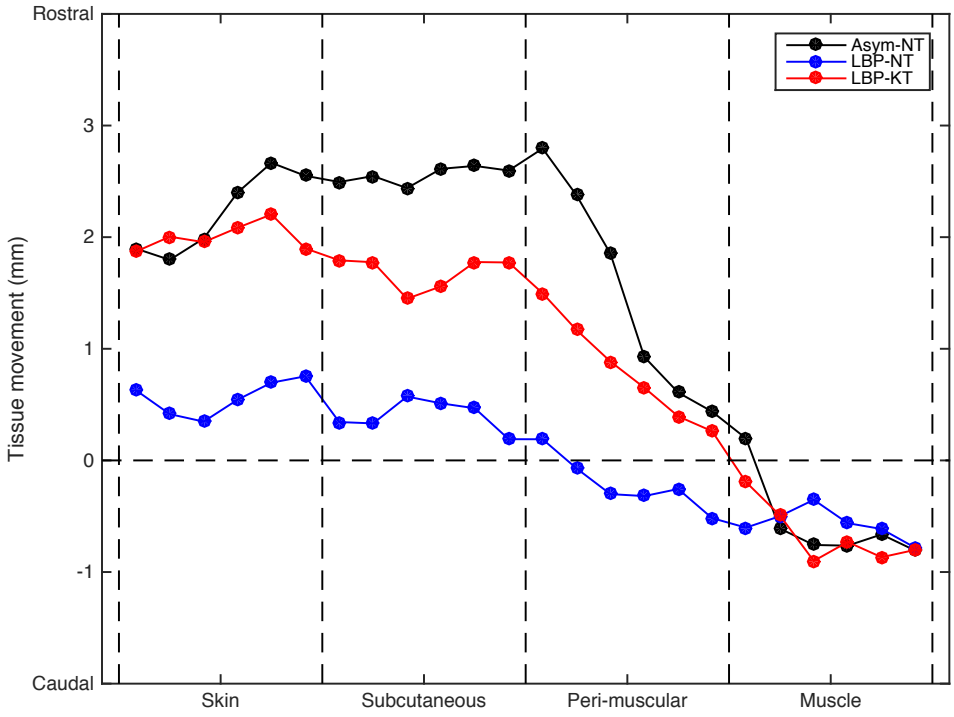


Figure** 85**. Tissue movements in sagittal plane against zones of the soft tissue (depth) in the phase of neutral to flexion – without error bars.

This graph demonstrates that the soft tissue movement pattern of people with LBP were closer to the corresponding movement pattern of asymptomatic participants. Asym= asymptomatic; LBP= with lower back pain; NT= no taping (data in blue); KT= with KT (data in red);

Range of motion is one of the most commonly used patient outcomes for back pain in physiotherapy. Gonzalez-Iglesias et al. (2009) and Yoshida and Kahanov (2007) reported small improvements in ROM after participants received KT applications, but the effect of KT on ROM improvements remains unclear due to many concerns, which have been discussed in Chapter 1.2.2.1. In the present project, KT can neither improve lumbar flexion in asymptomatic participants nor in people with LBP, despite a small improvement trend seen in the data. However, the changes in soft tissue dynamic are a more important factor when discussing the actual mechanisms of KT. With no change on the overall range of motion, the changes are more likely to reflect soft tissue response to KT applications. In contrast, it would be difficult to confirm if changes in overall ROM and tissue movement were observed at the same time.

7.1.4.2 Multiple conditions

Posture and loading during lumbar flexion are believed to be correlated with LBP, as postures change the loading on the vertebral bodies and discs (Nachemson, 1981, Wilke et al., 1999).

Soft tissue dynamics were also observed in this project as additional measurements to explore whether posture and load baring also influence soft tissue biomechanics. It is also important to know if observed effects of KT during normal lumbar flexion remain the same when posture and trunk loading changed during the movement. The overall range of motion reduced by about 20 degrees when participants performing the movement task in a seated condition (Chapter 6.3.3). This reduction was due to the limitation of pelvis tilt in a seated posture, the tissue movements were, therefore, reduced simultaneously. Since neither difference in tissue biomechanics nor in range of motion was found after KT application, KT may not be able to change tissue dynamic with such a small overall movement. No significant difference in soft tissue biomechanics during both the concentric and eccentric phases of the lumbar flexion. This potentially suggests that the KT tension might not be strong enough to overcome stronger muscle contraction. This finding can be a potential mechanism to explain the outcome of a previous study which reported using tape tension designed to generate skin convolutions did not deliver a better treatment outcome (Parreira et al., 2014b). Soft tissue movements of people with LBP exhibit similar pattern with asymptomatic participants when reducing trunk loading. This may indicate that reducing trunk load during movement can help with the condition. Although the evidence discovered in the present project was not sufficient to confirm this hypothesis conclusively, reducing trunk load may have 'reset' the tissue adhesion so tissue has more freedom to move. It is important to compare this result with the ultrasound elastography assessment in future studies.

The multi-condition observational studies were conducted as an additional part of this project. The aim was to discover if soft-tissue biomechanics play any key role in common concerns such as postural compensation or reduced trunk loading to reduce pain and to see if KT is potentially useful for these outcomes. The results were not suggestive of further direction for these selected conditions, however, it was still important to discover whether sub-groups of the LBP cohort could be identified using the data of usual lumbar flexion movement task.

7.1.5 Attempting to complete the puzzle: sub-group exploration

Observational studies demonstrated different thoracolumbar tissue responses to KT application in people with and without LBP, although the evidence was weak due to the underpowered statistical test. The ultimate goal to achieve is to decide either to improve KT treatment methods or remove KT from the toolbox of LBP treatment. Further information is therefore required to make this final decision. VAS improvement was used to split participants with LBP into responder and non-responder sub-group. Figure 86 demonstrates

an additional step of sub-group exploration which linked the observational work and informed the final decision making.

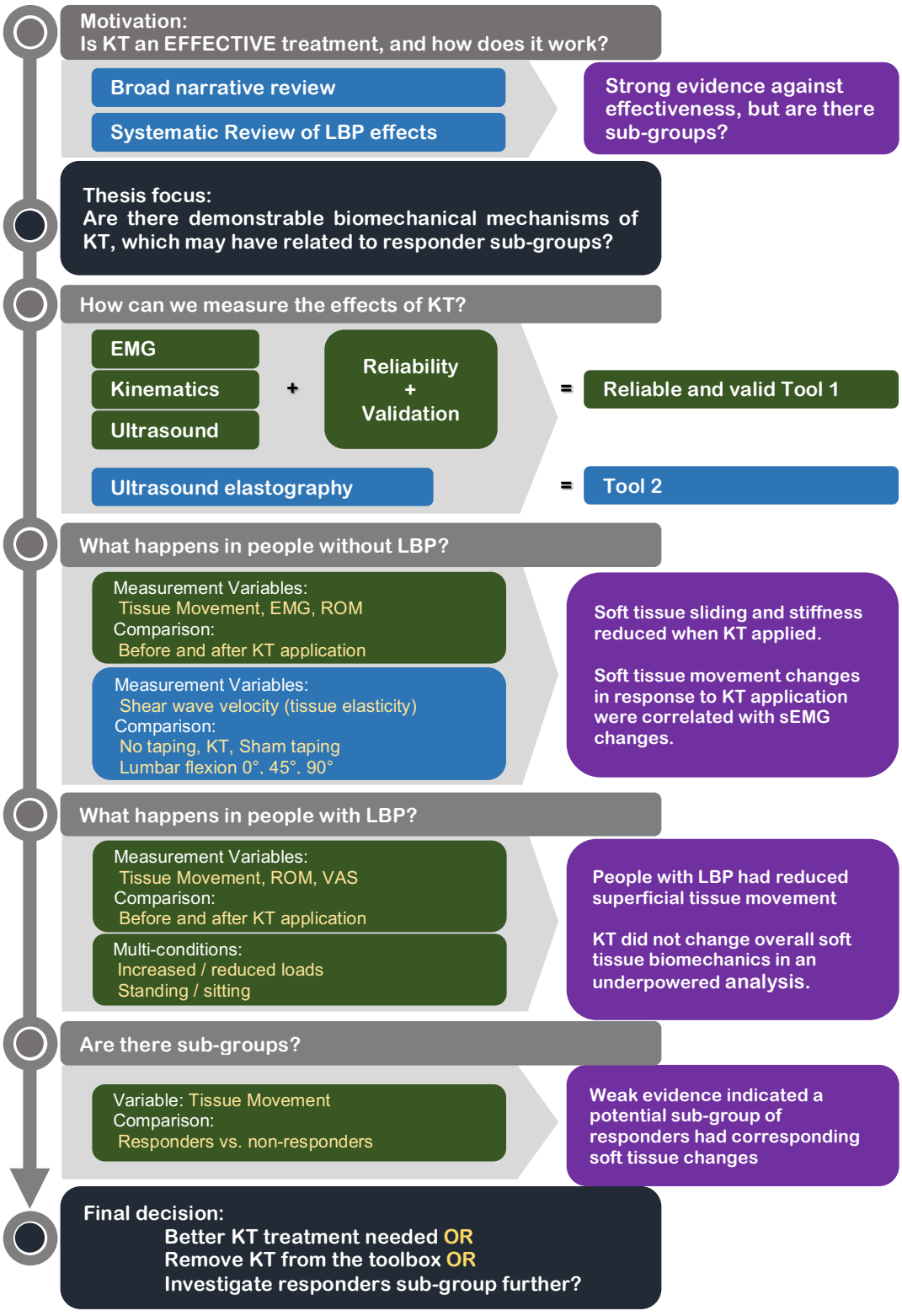


Figure 86. Demonstrates the whole flow of this project and indicated the final and future directions.

The MANOVA showed a significant difference in the linear combination of tissue movement in all zones between responders and non-responders. Although subsequent univariate tests showed no significance due partly to a lack of power, this result promised the potential value of discovering subgroups (in reflection of Aim and Objective 6, pp.20). Subgrouping is considered as an important factors in many other conditions and treatments. Analogies might be drawn with arthroscopic meniscal repair surgery, for example, where current evidence does not encourage middle-aged patients to receive surgery as the success rate is rather low (Herrlin et al., 2013, Sihvonen et al., 2013). While, there are better results for younger patents in sports and other occupations (Abrams et al., 2013, Stärke et al., 2009). Apart from subgrouping by age, different types of meniscal injury mechanisms, such as traumatic or degenerative, are usually considered as a subgrouping factor (Herrlin et al., 2013, Stärke et al., 2009). A similar principle should be considered when applying KT as an adjunct in LBP care. The results suggested that soft tissue response should be considered as a potential factor to identify proper subgrouping for KT treatment.

7.1.5.1 Limitations

There were a few limitations in this sub-group exploration. The sample size was rather small when participants with LBP were divided into two sub-groups. As the sub-group discovery was a later decision in my PhD project, study time was not sufficient to recruit more people with acute LBP. Additionally, KT responders can only be identified when the test-retest procedure has been performed which is another challenge in responder recruitment.

The other potential concern was that participants with LBP involved in the sub-group experiments and analysis only had minor to mild LBP. The mean VAS score before KT was 2.69 ± 1.07. Literature suggested that an improvement of 2 out of ten in VAS is required to be considered as a clinically relevant improvement (Farrar et al., 2001, Hägg et al., 2003). There was not much space for improvement with such a low baseline in VAS assessment. I, therefore, have to consider the immediate improvement in pain from 0.4 to 1.6 cm as my responder group index to perform between-subject comparisons.

7.2 Future directions

The most critical limitation of this project was statistical power. The comparisons between asymptomatic and LBP participants and the comparisons before and after KT application were underpowered due to the low numbers, augmented by the large standard errors in ultrasound measurements. The large variability can be a common feature of soft tissue movement since multiple joints and layers of tissues involved in lumbar flexion enable a large

number of degrees of freedom. This is a common difficulty in LBP studies, as investigators do not have a precise observation target due to most cases of LBP being non-specific (Airaksinen et al., 2006, Van Tulder et al., 2006). Nevertheless, the consistent phantom testing result promised that the potential assessment error had been well controlled. Furthermore, the preliminary subgroups exploration suggested that future study of a bigger sample size of LBP patients with responders and non-responders or a longitudinal clinical trial with mechanistic exploration, based on the findings of this series of snapshot observation works, should be considered in order to secure the statistical power and establish effects without the effect of confounding variables and bias.

To contribute robust clinical recommendations, future study should focus on biomechanical exploration from those whose condition immediately benefit from receiving KT, and proceed to examine if any biomechanical parameter can be developed as an index to determine a specific type of patient who is more likely to be benefit from receiving KT application during rehabilitation. Patients who have a marked increase in otherwise restricted ROM of the lumbar flexion may be a particular focus of investigation – more commonly the case with more severe LBP. Therefore, further ultrasound-based assessment tool development based on the findings of present thesis are worthwhile continuing as ultrasound is an ideal clinically applied tool comparing to MRI - which is currently recommended by the European clinical guideline for LBP (Airaksinen et al., 2006). These works, which include exploration of new diagnostic tool possibilities and improvement of current treatment approaches, would ultimately indicate a direction to improve current LBP care.

Although the focus of this thesis is to explore the actual mechanisms of KT. The ultrasound-based assessment procedure for the soft tissue dynamics can be considered as a potential tool to be used in other areas of sports medicine. This method is extensively transferable for all soft tissue related studies, such as manual therapy or other alternative therapeutics. Similarly, based on the present project, this method has the potential to be further developed as an assessment tool for clinicians as an aid for treatment plan making. For example, to develop a criteria to determine certain types of patients who are more likely to benefit from receiving soft tissue treatments.

7.3 Conclusions

The literature review indicated that current evidence does not support the clinical effect of KT, and mechanisms of its action is a missing part. This thesis delivered an innovative, reliable measurement approach, which was accurate enough to investigate a potential mechanism

explaining KT effects in LBP. The outcomes of each step, discussed in this chapter, showed that some effects of a common KT procedure on the thoracolumbar soft tissues were demonstrable. Although the observed differences in tissue dynamics are not yet clinically applicable, mixed methods showed that KT is likely to alter soft tissue movement patterns and biomechanical properties in people with and without LBP. Weak evidence showed that people with and without LBP have different soft tissue responses to KT. These findings, therefore, informed the sub-group exploration, indicating that KT responders, who reported immediate LBP relief after KT application, may have different soft tissue responses in comparison with non-responders. The evidence was not powerful enough to draw a robust positive conclusion, hence future study should focus on the biomechanical exploration from those whose condition immediately benefit from receiving KT, and proceed to examine if any biomechanical parameter – ideally easily clinically applied - can be developed as an index to determine sub-groups who are more likely to be benefit from receiving KT application during rehabilitation. These findings indicate directions worthy of pursing to improve current LBP care with KT.

In summary, this thesis provides useful contributions to the filed, particularly in expoloring the mechanisms of KT when applied to the lower back region. It is noted that findings need to be seen as indicative only, due to the fact that pilot trials did not have sufficient statistical power to provide breaking through evidence. However, this thesis provides useful contributions to the field, particularly in exploring the mechanisms of KT when applied to the lower back region. These contributions are a thorough and critical investigation of the current research into the effects of KT on human performance and well-being; the development of a novel real-time capable tools to measure soft tissue movement during body motion; new findings indicating potential effects of KT on people with LBP and the ability to identify responders in test subjects using the developed tools; and finally, a thorough experimental study on human participants setting the foundation for future research in related areas.

REFERENCES

ABRAMS, G. D., FRANK, R. M., GUPTA, A. K., HARRIS, J. D., MCCORMICK, F. M. & COLE, B. J. 2013. Trends in Meniscus Repair and Meniscectomy in the United States, 2005-2011. *The American Journal of Sports Medicine,* 41**,** 2333-2339.

ADAMCZYK, A., KIEBZAK, W., WILK-FRAŃCZUK, M. & SLIWIŃSKI, Z. 2008. Effectiveness of holistic physiotherapy for low back pain. *Ortopedia, Traumatologia, Rehabilitacja,* 11**,** 562-576.

ADDED, M. A., COSTA, L. O., FUKUDA, T. Y., DE FREITAS, D. G., SALOMAO, E. C., MONTEIRO, R. L. & COSTA, L. D. A. 2013. Efficacy of adding the kinesio taping method to guideline-endorsed conventional physiotherapy in patients with chronic nonspecific low back pain: A randomised controlled trial. *BMC Musculoskeletal Disorders,* 14**,** 301.

AIRAKSINEN, O., BROX, J. I., CEDRASCHI, C., HILDEBRANDT, J., KLABER-MOFFETT, J., KOVACS, F., MANNION, A. F., REIS, S., STAAL, J. & URSIN, H. 2006. Chapter 4 European guidelines for the management of chronic nonspecific low back pain. *European spine journal,* 15**,** s192-s300.

AKBAS, E., ATAY, A. O. & YUKSEL, I. 2011. The effects of additional kinesio taping over exercise in the treatment of patellofemoral pain syndrome. *Acta orthopaedica et traumatologica turcica,* 45**,** 335-41.

AL-SHAREEF, A. T., OMAR, M. T. & IBRAHIM, A. H. 2016. Effect of Kinesio Taping on pain and functional disability in chronic nonspecific low back pain: a randomized clinical trial. *Spine,* 41**,** E821-E828.

ALBAHEL, F., HAFEZ, A. R., ZAKARIA, A. R., AL-AHAIDEB, A., BURAGADDA, S. & MELAM, G. R. 2013. Kinesio taping for the treatment of mechanical low back pain. *World Applied Science Journal,* 22**,** 78-84.

ÁLVAREZ-ÁLVAREZ, S., SAN JOSÉ, F., RODRÍGUEZ-FERNÁNDEZ, A., GÜEITA-RODRÍGUEZ, J. & WALLER, B. 2014. Effects of Kinesio® Tape in low back muscle fatigue: randomized, controlled, doubled-blinded clinical trial on healthy subjects. *Journal of Back and Musculoskeletal Rehabilitation,* 27**,** 203-212.

ASTHANA, D., NIJHAWAN, A. & KUPPUSWAMY, R. 2013. Effectiveness of kinesiotaping in improving pain, lumbar extension range of motion and disability in patients with chronic non specific low back pain. *Intrnation Journal of Physiotherapy and Research,* 1**,** 293-299.

AYTAR, A., OZUNLU, N., SURENKOK, O., BALTACI, G., OZTOP, P. & KARATAS, M. 2011. Initial effects of kinesio (R) taping in patients with patellofemoral pain syndrome: A randomized, double-blind study. *Isokinetics and Exercise Science,* 19**,** 135-142.

BAE, S. H., LEE, J. H., OH, K. A. & KIM, K. Y. 2013. The effects of kinesio taping on potential in chronic low back pain patients anticipatory postural control and cerebral cortex. *Journal of Physical Therapy Science,* 25**,** 1367-71.

BAKHTIARY, A. H., AMINIANFAR, A., AKBARZADEH, Z. & SHEIKHIAN-AZIZI, S. 2015. Effects of kinesio taping on pain and functional disability in young female with menstrual low back pain. *Koomesh,* 16**,** 404-412.

BALAGUE, F., TROUSSIER, B. & SALMINEN, J. 1999. Non-specific low back pain in children and adolescents: risk factors. *European Spine Journal,* 8**,** 429-438.

BAMBER, J., COSGROVE, D., DIETRICH, C., FROMAGEAU, J., BOJUNGA, J., CALLIADA, F., CANTISANI, V., CORREAS, J.-M., D'ONOFRIO, M. & DRAKONAKI, E. 2013. EFSUMB guidelines and recommendations on the clinical use of ultrasound elastography. Part

1: Basic principles and technology. *Ultraschall in der Medizin-European Journal of Ultrasound,* 34**,** 169-184.

BELL, A. L., PEDERSEN, D. R. & BRAND, R. A. 1990. A comparison of the accuracy of several hip center location prediction methods. *Journal of biomechanics,* 23**,** 617-621.

BERCOFF, J., TANTER, M. & FINK, M. 2004. Supersonic shear imaging: a new technique for soft tissue elasticity mapping. *IEEE transactions on ultrasonics, ferroelectrics, and frequency control,* 51**,** 396-409.

BISHOP, J. H., FOX, J. R., MAPLE, R., LORETAN, C., BADGER, G. J., HENRY, S. M., VIZZARD, M. A. & LANGEVIN, H. M. 2016. Ultrasound Evaluation of the Combined Effects of Thoracolumbar Fascia Injury and Movement Restriction in a Porcine Model. *PLOS ONE,* 11**,** e0147393.

BODENHEIMER, B., ROSE, C., ROSENTHAL, S. & PELLA, J. 1997. The Process of Motion Capture: Dealing with the Data. *In:* THALMANN, D. & VAN DE PANNE, M. (eds.) *Computer Animation and Simulation '97.* Springer Vienna.

BOUDREAU, S. N., DWYER, M. K., MATTACOLA, C. G., LATTERMANN, C., UHL, T. L. & MCKEON, J. M. 2009. Hip-muscle activation during the lunge, single-leg squat, and step-up-and-over exercises. *J Sport Rehabil,* 18**,** 91-103.

BRESSLER, H. B., KEYES, W. J., ROCHON, P. A. & BADLEY, E. 1999. The prevalence of low back pain in the elderly: a systematic review of the literature. *Spine,* 24**,** 1813.

CALLAGHAN, J. P. & DUNK, N. M. 2002. Examination of the flexion relaxation phenomenon in erector spinae muscles during short duration slumped sitting. *Clinical Biomechanics,* 17**,** 353-360.

CAPPOZZO, A., CAPPELLO, A., CROCE, U. D. & PENSALFINI, F. 1997. Surface-marker cluster design criteria for 3-D bone movement reconstruction. *IEEE Transactions on Biomedical Engineering,* 44**,** 1165-1174.

CAPPOZZO, A., CATANI, F., DELLA CROCE, U. & LEARDINI, A. 1995. Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics,* 10**,** 171-178.

CASTRO-SÁNCHEZ, A. M., LARA-PALOMO, I. C., MATARÁN- PEÑARROCHA, G. A., FERNÁNDEZ-SÁNCHEZ, M., SÁNCHEZ-LABRACA, N. & ARROYO-MORALES, M. 2012. Kinesio Taping reduces disability and pain slightly in chronic non-specific low back pain: a randomised trial. *Journal of Physiotherapy,* 58**,** 89-95.

CESERACCIU, E., SAWACHA, Z. & COBELLI, C. 2014. Comparison of markerless and marker-based motion capture technologies through simultaneous data collection during gait: proof of concept. *PloS One,* 9**,** e87640.

CHANG, H. Y., CHOU, K. Y., LIN, J. J., LIN, C. F. & WANG, C. H. 2010. Immediate effect of forearm Kinesio taping on maximal grip strength and force sense in healthy collegiate athletes. *Physical Therapy in Sport,* 11**,** 122-127.

CHANG, N.-J., CHOU, W., HSIAO, P.-C., CHANG, W.-D. & LO, Y.-M. 2018. Acute effects of Kinesio taping on pain, disability and back extensor muscle endurance in patients with low back pain caused by magnetic resonance imaging-confirmed lumbar disc degeneration. *Journal of Back and Musculoskeletal Rehabilitation,* 31**,** 85-93.

CHAPARRO, L. E., FURLAN, A. D., DESHPANDE, A., MAILIS-GAGNON, A., ATLAS, S. & TURK, D. C. 2013. Opioids compared to placebo or other treatments for chronic low-back pain. *Cochrane Database Syst Rev,* 8**,** Cd004959.

CHARNWOOD DYNAMICS LTD 2004. CODA CX1 User Guide. Leicestershire, UK.

CHARNWOOD DYNAMICS LTD 2014. ODIN - the ultimate motion capture software user guide. 1.5 ed. Leicestershire, UK: Charnwood Dynamics Ltd.

CHAUDHRY, H., SCHLEIP, R., JI, Z., BUKIET, B., MANEY, M. & FINDLEY, T. 2008. Three-Dimensional Mathematical Model for Deformation of Human Fasciae in Manual Therapy. *The Journal of the American Osteopathic Association,* 108**,** 379-390.

CHEN, S., FATEMI, M. & GREENLEAF, J. F. 2004. Quantifying elasticity and viscosity from measurement of shear wave speed dispersion. *The Journal of the Acoustical Society of America,* 115**,** 2781-2785.

CHEN, S.-M., ALEXANDER, R., LO, S. K. & COOK, J. 2012. Effects of Functional Fascial Taping on pain and function in patients with non-specific low back pain: a pilot randomized controlled trial. *Clinical Rehabilitation,* 26**,** 924-933.

CHEN, W., LOU, E. H. & LE, L. H. Using ultrasound imaging to identify landmarks in vertebra models to assess spinal deformity. Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE, 2011. IEEE, 8495-8498.

CHERNAK, L., DEWALL, R., LEE, K. & THELEN, D. 2013. Length and activation dependent variations in muscle shear wave speed. *Physiological Measurement,* 34**,** 713.

CHEUNG, J. T.-M., ZHANG, M. & AN, K.-N. 2006. Effect of Achilles tendon loading on plantar fascia tension in the standing foot. *Clinical Biomechanics,* 21**,** 194-203.

CICCHETTI, D. V. 1994. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological Assessment,* 6**,** 284.

COHEN, J. 1992. A power primer. *Psychological Bulletin,* 112**,** 155.

CORDOVA, M., INGERSOLL, C. & LEBLANC, M. 2000. Influence of ankle support on joint range of motion before and after exercise: a meta-analysis. *The Journal of Orthopaedic and Sports Physical Therapy,* 30**,** 170-7; discussion 178-82.

COSGROVE, D., PISCAGLIA, F., BAMBER, J., BOJUNGA, J., CORREAS, J.-M., GILJA, O., KLAUSER, A., SPOREA, I., CALLIADA, F. & CANTISANI, V. 2013. EFSUMB guidelines and recommendations on the clinical use of ultrasound elastography. Part 2: Clinical applications. *Ultraschall in der Medizin-European Journal of Ultrasound,* 34**,** 238-253.

COSTA, L. D. C. M., MAHER, C. G., HANCOCK, M. J., MCAULEY, J. H., HERBERT, R. D. & COSTA, L. O. P. 2012. The prognosis of acute and persistent low-back pain: a meta-analysis. *Canadian Medical Association Journal*.

COUADE, M., PERNOT, M., PRADA, C., MESSAS, E., EMMERICH, J., BRUNEVAL, P., CRITON, A., FINK, M. & TANTER, M. 2010. Quantitative assessment of arterial wall biomechanical properties using shear wave imaging. *Ultrasound in Medicine and Biology,* 36**,** 1662-1676.

D'HOOGE, R., HODGES, P., TSAO, H., HALL, L., MACDONALD, D. & DANNEELS, L. 2013. Altered trunk muscle coordination during rapid trunk flexion in people in remission of recurrent low back pain. *Journal of Electromyography and Kinesiology,* 23**,** 173-181.

DALY, C. 2017. *Biomechanical factors associated with previous hamstring injury in high level sprinting athletes.* Queen Mary University of London.

DE LUCA, C. J., KLINE, J. C. & CONTESSA, P. 2014. Transposed firing activation of motor units. *Journal of Neurophysiology,* 112**,** 962-970.

DE ZORDO, T., FINK, C., FEUCHTNER, G. M., SMEKAL, V., REINDL, M. & KLAUSER, A. S. 2009. Real-Time Sonoelastography Findings in Healthy Achilles Tendons. *American Journal of Roentgenology,* 193**,** W134-W138.

DELITTO, A., GEORGE, S. Z., VAN DILLEN, L. R., WHITMAN, J. M., SOWA, G., SHEKELLE, P., DENNINGER, T. R. & GODGES, J. J. 2012. Low back pain. *Journal of Orthopaedic and Sports Physical Therapy,* 42**,** A1-57.

DELMORE, R. J., LAUDNER, K. G. & TORRY, M. R. 2014. Adductor longus activation during common hip exercises. *J Sport Rehabil,* 23**,** 79-87.

DILLEY, A., GREENING, J., LYNN, B., LEARY, R. & MORRIS, V. 2001. The use of cross-correlation analysis between high-frequency ultrasound images to measure longitudinal median nerve movement. *Ultrasound in medicine & biology,* 27**,** 1211-1218.

DIVANI, K., CHAN, O., PADHIAR, N., TWYCROSS-LEWIS, R., MAFFULLI, N., CRISP, T. & MORRISSEY, D. 2010. Site of maximum neovascularisation correlates with the site of pain in recalcitrant mid-tendon Achilles tendinopathy. *Manual Therapy,* 15**,** 463-468.

DROST, G., STEGEMAN, D. F., SCHILLINGS, M. L., HOREMANS, H. L., JANSSEN, H. M., MASSA, M., NOLLET, F. & ZWARTS, M. J. 2004. Motor unit characteristics in healthy subjects and those with postpoliomyelitis syndrome: A high-density surface EMG study. *Muscle & Nerve,* 30**,** 269-276.

DROST, G., STEGEMAN, D. F., VAN ENGELEN, B. G. & ZWARTS, M. J. 2006. Clinical applications of high-density surface EMG: a systematic review. *Journal of Electromyography and Kinesiology,* 16**,** 586-602.

DYER, S., MARTIN, J. & ZULAUF, J. 1995. Motion capture white paper.

EBBEHØJ, N., HANSEN, F., HARREBY, M. & LASSEN, C. 2002. [Low back pain in children and adolescents. Prevalence, risk factors and prevention]. *Ugeskrift for laeger,* 164**,** 755-758.

EMERSON, C., MORRISSEY, D., PERRY, M. & JALAN, R. 2010. Ultrasonographically detected changes in Achilles tendons and self reported symptoms in elite gymnasts compared with controls – An observational study. *Manual Therapy,* 15**,** 37-42.

ENGERS, A. J., JELLEMA, P., WENSING, M., VAN DER WINDT, D. A., GROL, R. & VAN TULDER, M. W. 2008. Individual patient education for low back pain. *Cochrane Database of Systematic Reviews*.

FAIRBANK, J. C. T. & PYNSENT, P. B. 2000. The Oswestry disability index. *Spine,* 25**,** 2940.

FARINA, D. & FALLA, D. 2008. Estimation of muscle fiber conduction velocity from two-dimensional surface EMG recordings in dynamic tasks. *Biomedical Signal Processing and Control,* 3**,** 138-144.

FARINA, D., GAZZONI, M. & MERLETTI, R. 2003. Assessment of low back muscle fatigue by surface EMG signal analysis: methodological aspects. *Journal of Electromyography and Kinesiology,* 13**,** 319-332.

FARRAR, J. T., YOUNG, J. P., LAMOREAUX, L., WERTH, J. L. & POOLE, R. M. 2001. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. *Pain,* 94**,** 149-158.

FELICI, F., COLACE, L. & SBRICCOLI, P. 1997. Surface EMG modifications after eccentric exercise. *J Electromyogr Kinesiol,* 7**,** 193-202.

FRANCHI-ABELLA, S., ELIE, C. & CORREAS, J. M. 2013. Ultrasound elastography: Advantages, limitations and artefacts of the different techniques from a study on a phantom. *Diagnostic and Interventional Imaging,* 94**,** 497-501.

FU, T. C., WONG, A. M. K., PEI, Y. C., WU, K. P., CHOU, S. W. & LIN, Y. C. 2008. Effect of Kinesio taping on muscle strength in athletes - A pilot study. *Journal of Science and Medicine in Sport,* 11**,** 198-201.

GABAI, O. & PRIMO, H. 2011. Acoustic motion capture. Google Patents.

GE HEALTHCARE 2007. Volusion i Basic User Manual. Austria: GE Healthcare.

GEISSER, M. E., HAIG, A. J., WALLBOM, A. S. & WIGGERT, E. A. 2004. Pain-related fear, lumbar flexion, and dynamic EMG among persons with chronic musculoskeletal low back pain. *The Clinical Journal of Pain,* 20**,** 61-69.

GENERAL ASSEMBLY OF THE WORLD MEDICAL ASSOCIATION 2014. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *The Journal of the American College of Dentists,* 81**,** 14.

GIBSON, W., ARENDT-NIELSEN, L., TAGUCHI, T., MIZUMURA, K. & GRAVEN-NIELSEN, T. 2009. Increased pain from muscle fascia following eccentric exercise: animal and human findings. *Experimental Brain Research,* 194**,** 299.

GÓMEZ-SORIANO, J., ABIÁN-VICÉN, J., APARICIO-GARCÍA, C., RUIZ-LÁZARO, P., SIMÓN-MARTÍNEZ, C., BRAVO-ESTEBAN, E. & FERNÁNDEZ-RODRÍGUEZ, J. M. 2014. The

effects of Kinesio taping on muscle tone in healthy subjects: a double-blind, placebo-controlled crossover trial. *Manual Therapy,* 19**,** 131-136.

GONZÁLEZ ENCISO, J. R. 2009. Does kinesio taping improve the functionality and pain relief of people with non specific low back pain. *Evidence Based Practice III-2 (2009) European School of Physiotherapy (ESP), Hogeschool van Amsterdam, The Netherlands*.

GONZALEZ-IGLESIAS, J., FERNANDEZ-DE-LAS-PENAS, C., CLELAND, J., HUIJBREGTS, P. & DEL ROSARIO, G. V. M. 2009. Short-term effects of cervical kinesio taping on pain and cervical range of motion in patients with acute whiplash injury: a randomized clinical trial. *The Journal of Orthopaedic and Sports Physical Therapy,* 39**,** 515.

GRIGG, P. 1994. Peripheral neural mechanisms in proprioception. *Journal of Sport Rehabilitation,* 3**,** 2-17.

HÄGG, O., FRITZELL, P. & NORDWALL, A. 2003. The clinical importance of changes in outcome scores after treatment for chronic low back pain. *European Spine Journal,* 12**,** 12-20.

HAIDICH, A. B. 2010. Meta-analysis in medical research. *Hippokratia,* 14**,** 29-37.

HALSETH, T., MCCHESNEY, J. W., DEBELISO, M., VAUGHN, R. & LIEN, J. 2004. The effects of kinesio™ taping on proprioception at the ankle. *Journal of Sports Science & Medicine,* 3**,** 1.

HAWKER, G. A., MIAN, S., KENDZERSKA, T. & FRENCH, M. 2011. Measures of adult pain: Visual analog scale for pain (vas pain), numeric rating scale for pain (nrs pain), mcgill pain questionnaire (mpq), short-form mcgill pain questionnaire (sf-mpq), chronic pain grade scale (cpgs), short form-36 bodily pain scale (sf-36 bps), and measure of intermittent and constant osteoarthritis pain (icoap). *Arthritis Care & Research,* 63.

HAYDEN, J. A., CARTWRIGHT, J. L., RILEY, R. D. & VANTULDER, M. W. 2012. Exercise therapy for chronic low back pain: protocol for an individual participant data meta-analysis. *Syst Rev,* 1**,** 64.

HEBERT, J. J., KOPPENHAVER, S. L., PARENT, E. C. & FRITZ, J. M. 2009. A systematic review of the reliability of rehabilitative ultrasound imaging for the quantitative assessment of the abdominal and lumbar trunk muscles. *Spine,* 34.

HEDAYATPOUR, N., FALLA, D., ARENDT-NIELSEN, L. & FARINA, D. 2008. Sensory and electromyographic mapping during delayed-onset muscle soreness. *Medicine and Science in Sports and Exercise,* 40**,** 326-334.

HERBERT, R., MOSELEY, A., BUTLER, J. & GANDEVIA, S. 2002. Change in length of relaxed muscle fascicles and tendons with knee and ankle movement in humans. *The Journal of physiology,* 539**,** 637-645.

HERMENS, H., BRUGGEN, T., BATEN, C., RUTTEN, W. & BOOM, H. 1992. The median frequency of the surface EMG power spectrum in relation to motor unit firing and action potential properties. *Journal of Electromyography and Kinesiology,* 2**,** 15-25.

HERMENS, H. J., FRERIKS, B., MERLETTI, R., STEGEMAN, D., BLOK, J., RAU, G., DISSELHORST-KLUG, C. & HÄGG, G. 1999. European recommendations for surface electromyography. *Roessingh research and development,* 8**,** 13-54.

HERRLIN, S. V., WANGE, P. O., LAPIDUS, G., HÅLLANDER, M., WERNER, S. & WEIDENHIELM, L. 2013. Is arthroscopic surgery beneficial in treating non-traumatic, degenerative medial meniscal tears? A five year follow-up. *Knee Surgery, Sports Traumatology, Arthroscopy,* 21**,** 358-364.

HESTBAEK, L., LEBOEUF-YDE, C. & MANNICHE, C. 2003. Low back pain: what is the long-term course? A review of studies of general patient populations. *European Spine Journal,* 12**,** 149-165.

HOY, D., BROOKS, P., BLYTH, F. & BUCHBINDER, R. 2010. The Epidemiology of low back pain. *Best Practice & Research Clinical Rheumatology,* 24**,** 769-781.

HSU, Y.-H., CHEN, W.-Y., LIN, H.-C., WANG, W. T. & SHIH, Y.-F. 2009. The effects of taping on scapular kinematics and muscle performance in baseball players with shoulder impingement syndrome. *Journal of Electromyography and Kinesiology,* 19**,** 1092-1099.

HUG, F., OUELLETTE, A., VICENZINO, B., HODGES, P. W. & TUCKER, K. 2014. Deloading tape reduces muscle stress at rest and during contraction. *Medicine & Science in Sports & Exercise,* 46**,** 2317-2325.

JACOBSON, J. A. 2009. Musculoskeletal ultrasound: focused impact on MRI. *American Journal of Roentgenology,* 193**,** 619-627.

KACHANATHU, S. J., ALENAZI, A. M., SEIF, H. E., HAFEZ, A. R. & ALROUMIM, M. A. 2014. Comparison between Kinesio Taping and a Traditional Physical Therapy Program. *J Phys Ther Sci,* 26**,** 1185-8.

KALRON, A. & BAR-SELA, S. 2013. A systematic review, of the effectiveness of Kinesio Taping (R) - Fact or fashion? *European Journal of Physical and Rehabilitation Medicine,* 49**,** 699-709.

KAPLAN, Ş., ALPAYCI, M., KARAMAN, E., ÇETIN, O., ÖZKAN, Y., İLTER, S., ŞAH, V. & ŞAHIN, H. G. 2016. Short-term effects of Kinesio taping in women with pregnancy-related low back pain: A randomized controlled clinical trial. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research,* 22**,** 1297.

KARABAY, N., TOROS, T. & HUREL, C. 2007. Ultrasonographic Evaluation in Plantar Fasciitis. *The Journal of Foot and Ankle Surgery,* 46**,** 442-446.

KASE, K. & WALLIS, J. 2002. The latest kinesio taping method. *Tokyo: Ski-Journal*.

KASE, K., WALLIS, J. & KASE, T. 2003. *Clinical therapeutic applications of the kinesio taping method*, Kinesio Taping Association.

KAYA, E., ZINNUROGLU, M. & TUGCU, I. 2011. Kinesio taping compared to physical therapy modalities for the treatment of shoulder impingement syndrome. *Clinical Rheumatology,* 30**,** 201-207.

KELLE, B., GÜZEL, R. & SAKALLI, H. 2016. The effect of Kinesio taping application for acute non-specific low back pain: A randomized controlled clinical trial. *Clin Rehabil,* 30**,** 997-1003.

KHADILKAR, A., ODEBIYI, D. O., BROSSEAU, L. & WELLS, G. A. 2008. Transcutaneous electrical nerve stimulation (TENS) versus placebo for chronic low-back pain. *Cochrane Database Syst Rev***,** Cd003008.

KILLIAN, B., NORDEZ, A. & HUG, F. 2011. Estimation of Individual Muscle Force Using Elastography. *PLoS ONE,* 6**,** e29261.

KIM, C. H., KIM, A. R., KIM, M. I., KIM, S. H., YOO, H. J. & LEE, S. H. 2002. The efficacy of Kinesio taping in patients with a low back pain. *Journal of the Korean Academy of Family Medicine,* 23**,** 197-204.

KLAUSER, A. S., FASCHINGBAUER, R. & JASCHKE, W. R. 2010. Is Sonoelastography of Value in Assessing Tendons? *Semin Musculoskelet Radiol,* 14**,** 323-333.

KLAUSER, A. S., MIYAMOTO, H., BELLMANN-WEILER, R., FEUCHTNER, G. M., WICK, M. C. & JASCHKE, W. R. 2014. Sonoelastography: Musculoskeletal Applications. *Radiology,* 272**,** 622-633.

KLEINE, B. U., SCHUMANN, N. P., STEGEMAN, D. F. & SCHOLLE, H. C. 2000. Surface EMG mapping of the human trapezius muscle: the topography of monopolar and bipolar surface EMG amplitude and spectrum parameters at varied forces and in fatigue. *Clin Neurophysiol,* 111**,** 686-93.

KOES, B. W., VAN TULDER, M., LIN, C.-W. C., MACEDO, L. G., MCAULEY, J. & MAHER, C. 2010. An updated overview of clinical guidelines for the management of non-specific low back pain in primary care. *European Spine Journal,* 19**,** 2075-2094.

KONRAD, P. 2006. The ABC of EMG: A Practical Introduction to Kinesiological Electromyography. Version 1.4 ed.: Noraxon Inc. .

KOO, T. K., GUO, J.-Y., COHEN, J. H. & PARKER, K. J. 2013. Relationship between shear elastic modulus and passive muscle force: an ex-vivo study. *Journal of Biomechanics,* 46**,** 2053-2059.

LACOURPAILLE, L., HUG, F., BOUILLARD, K., HOGREL, J.-Y. & NORDEZ, A. 2012. Supersonic shear imaging provides a reliable measurement of resting muscle shear elastic modulus. *Physiological Measurement,* 33**,** N19.

LANGEVIN, H. M., FOX, J. R., KOPTIUCH, C., BADGER, G. J., GREENAN-NAUMANN, A. C., BOUFFARD, N. A., KONOFAGOU, E. E., LEE, W.-N., TRIANO, J. J. & HENRY, S. M. 2011. Reduced thoracolumbar fascia shear strain in human chronic low back pain. *BMC Musculoskeletal Disorders,* 12**,** 203.

LANGEVIN, H. M. & HUIJING, P. A. 2009. Communicating about fascia: history, pitfalls, and recommendations. *International Journal of Therapeutic Massage & Bodywork,* 2**,** 3.

LANGEVIN, H. M. & SHERMAN, K. J. 2007. Pathophysiological model for chronic low back pain integrating connective tissue and nervous system mechanisms. *Medical Hypotheses,* 68**,** 74-80.

LANGEVIN, H. M., STEVENS-TUTTLE, D., FOX, J. R., BADGER, G. J., BOUFFARD, N. A., KRAG, M. H., WU, J. & HENRY, S. M. 2009. Ultrasound evidence of altered lumbar connective tissue structure in human subjects with chronic low back pain. *BMC Musculoskeletal Disorders,* 10.

LAU, W. Y., BLAZEVICH, A. J., NEWTON, M. J., WU, S. S. X. & NOSAKA, K. 2015. Changes in electrical pain threshold of fascia and muscle after initial and secondary bouts of elbow flexor eccentric exercise. *European Journal of Applied Physiology,* 115**,** 959-968.

LEARDINI, A., CAPPOZZO, A., CATANI, F., TOKSVIG-LARSEN, S., PETITTO, A., SFORZA, V., CASSANELLI, G. & GIANNINI, S. 1999. Validation of a functional method for the estimation of hip joint centre location. *Journal of Biomechanics,* 32**,** 99-103.

LEE, C. R., LEE, D. Y., JEONG, H. S. & LEE, M. H. 2012. The Effects of Kinesio Taping on VMO and VL EMG Activities during Stair Ascent and Descent by Persons with Patellofemoral Pain: a Preliminary Study. *Journal of Physical Therapy Science,* 24**,** 153-156.

LEE, J.-H., YOO, W.-G. & LEE, K.-S. 2010. Effects of head-neck rotation and kinesio taping of the flexor muscles on dominant-hand grip strength. *Journal of Physical Therapy Science,* 22**,** 285-289.

LEE, J. H., YOO, W. G., KIM, M. H., OH, J. S., LEE, K. S. & HAN, J. T. 2014. Effect of posterior pelvic tilt taping in women with sacroiliac joint pain during active straight leg raising who habitually wore high-heeled shoes: a preliminary study. *J Manipulative Physiol Ther,* 37**,** 260-8.

LEMOS, T. V., ALBINO, A. C. G., MATHEUS, J. P. C. & BARBOSA, A. D. M. 2014. The Effect of Kinesio Taping in Forward Bending of the Lumbar Spine. *Journal of Physical Therapy Science,* 26**,** 1371-1375.

LEPHART, S. & FU, F. 1995. The role of proprioception in the treatment of sports injuries. *Sports Exercise and Injury,* 1**,** 96-102.

LEPHART, S. M., PINCIVERO, D. M., GIRAIDO, J. L. & FU, F. H. 1997. The role of proprioception in the management and rehabilitation of athletic injuries. *The American Journal of Sports Medicine,* 25**,** 130-137.

LIM, E. C. W. & TAY, M. G. X. 2015. Kinesio taping in musculoskeletal pain and disability that lasts for more than 4 weeks: is it time to peel off the tape and throw it out with the sweat? A systematic review with meta-analysis focused on pain and also methods of tape application. *Br J Sports Med,* 49**,** 1558-1566.

LOHR, K. N., AARONSON, N. K., ALONSO, J., AUDREY BURNAM, M., PATRICK, D. L., PERRIN, E. B. & ROBERTS, J. S. 1996. Evaluating quality-of-life and health status instruments: development of scientific review criteria. *Clinical Therapeutics,* 18**,** 979-992.

LOUKAS, M., SHOJA, M. M., THURSTON, T., JONES, V. L., LINGANNA, S. & TUBBS, R. S. 2008. Anatomy and biomechanics of the vertebral aponeurosis part of the posterior layer of the thoracolumbar fascia. *Surgical and Radiologic Anatomy,* 30**,** 125-129.

LUOMALA, T., PIHLMAN, M., HEISKANEN, J. & STECCO, C. 2014. Case study: Could ultrasound and elastography visualized densified areas inside the deep fascia? *Journal of Bodywork and Movement Therapies,* 18**,** 462-468.

LUZ JÚNIOR, M. A., SOUSA, M. V., NEVES, L. A., CEZAR, A. A. & COSTA, L. O. 2015. Kinesio Taping® is not better than placebo in reducing pain and disability in patients with chronic non-specific low back pain: a randomized controlled trial. *Brazilian Journal of Physical Therapy,* 19**,** 482-490.

LYONS, G. M., SHARMA, P., BAKER, M., O'MALLEY, S. & SHANAHAN, A. A computer game-based EMG biofeedback system for muscle rehabilitation. Engineering in Medicine and Biology Society, 2003. Proceedings of the 25th Annual International Conference of the IEEE, 17-21 Sept. 2003 2003. 1625-1628 Vol.2.

MACDONALD, D., MOSELEY, G. L. & HODGES, P. W. 2009. Why do some patients keep hurting their back? Evidence of ongoing back muscle dysfunction during remission from recurrent back pain. *PAIN®,* 142**,** 183-188.

MAHER, C. G., SHERRINGTON, C., HERBERT, R. D., MOSELEY, A. M. & ELKINS, M. 2003. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther,* 83**,** 713-21.

MAÏSETTI, O., HUG, F., BOUILLARD, K. & NORDEZ, A. 2012. Characterization of passive elastic properties of the human medial gastrocnemius muscle belly using supersonic shear imaging. *Journal of Biomechanics,* 45**,** 978-984.

MALANGA, G. A. & COLON, E. J. C. 2010. Myofascial low back pain: a review. *Physical Medicine and Rehabilitation Clinics of North America,* 21**,** 711-724.

MALLIARAS, P., KAMAL, B., NOWELL, A., FARLEY, T., DHAMU, H., SIMPSON, V., MORRISSEY, D., LANGBERG, H., MAFFULLI, N. & REEVES, N. D. 2013. Patellar tendon adaptation in relation to load-intensity and contraction type. *Journal of Biomechanics,* 46**,** 1893-1899.

MANCHIKANTI, L., SINGH, V., DATTA, S., COHEN, S. P. & HIRSCH, J. A. 2009. Comprehensive review of epidemiology, scope, and impact of spinal pain. *Pain Physician,* 12**,** E35-70.

MANNION, A. F., KNECHT, K., BALABAN, G., DVORAK, J. & GROB, D. 2004. A new skin-surface device for measuring the curvature and global and segmental ranges of motion of the spine: reliability of measurements and comparison with data reviewed from the literature. *European Spine Journal,* 13**,** 122-136.

MARTIN, B. I., DEYO, R. A., MIRZA, S. K., TURNER, J. A., COMSTOCK, B. A., HOLLINGWORTH, W. & SULLIVAN, S. D. 2008. Expenditures and health status among adults with back and neck problems. *Jama,* 299**,** 656-664.

MARTÍNEZ-GRAMAGE, J., MERINO-RAMIREZ, M., AMER-CUENCA, J. & LISÓN, J. 2016. Effect of Kinesio Taping on gastrocnemius activity and ankle range of movement during gait in healthy adults: a randomized controlled trial. *Physical Therapy in Sport,* 18**,** 56-61.

MARTINI, H. & BARTHOLOMEW, E. 2001. *Essentials of Anatomy and Physiology. 2nd*, Englewood Cliffs, NJ, USA: Prentice-Hall.

MATTOS, L. H. L., YAMADA, A. L. M., DOS SANTOS, V. H., HUSSNI, C. A., RODRIGUES, C. A., WATANABE, M. J. & ALVES, A. L. G. 2017. Treatment With Therapeutic Bandages to Control Equine Postarthroscopic Tibio-Patellofemoral Swelling. *Journal of Equine Veterinary Science,* 54**,** 87-92.

MCGINLEY, J. L., BAKER, R., WOLFE, R. & MORRIS, M. E. 2009. The reliability of three-dimensional kinematic gait measurements: A systematic review. *Gait & Posture,* 29**,** 360-369.

MERLETTI, R. & DI TORINO, P. 1999. Standards for reporting EMG data. *Journal of Electromyography and Kinesiology,* 9**,** 3-4.

MERLETTI, R., FARINA, D. & GAZZONI, M. 2003. The linear electrode array: a useful tool with many applications. *Journal of Electromyography and Kinesiology,* 13**,** 37-47.

MERLETTI, R. & PARKER, P. A. 2004. *Electromyography. Physiology, Engineering and Noninvasive Applications*, Wiley-Interscience.

MIYOSHI, T., KIHARA, T., KOYAMA, H., YAMAMOTO, S.-I. & KOMEDA, T. 2009. Automatic detection method of muscle fiber movement as revealed by ultrasound images. *Medical Engineering & Physics,* 31**,** 558-564.

MO, J., XU, H., QIANG, B., GIAMBINI, H., KINNICK, R., AN, K.-N., CHEN, S. & LUO, Z. 2016. Bias of shear wave elasticity measurements in thin layer samples and a simple correction strategy. *SpringerPlus,* 5**,** 1341.

MOESLUND, T. B., HILTON, A. & KRÜGER, V. 2006. A survey of advances in vision-based human motion capture and analysis. *Computer Vision and Image Understanding,* 104**,** 90-126.

MOHSENI-BANDPEI, M. A., NAKHAEE, M., MOUSAVI, M. E., SHAKOURIRAD, A., SAFARI, M. R. & VAHAB KASHANI, R. 2014. Application of Ultrasound in the Assessment of Plantar Fascia in Patients With Plantar Fasciitis: A Systematic Review. *Ultrasound in Medicine & Biology,* 40**,** 1737-1754.

MONAGHAN, K., DELAHUNT, E. & CAULFIELD, B. 2007. Increasing the number of gait trial recordings maximises intra-rater reliability of the CODA motion analysis system. *Gait and Posture,* 25**,** 303-315.

MORRIS, D., JONES, D., RYAN, H. & RYAN, C. 2013. The clinical effects of Kinesio® Tex taping: A systematic review. *Physiotherapy Theory and Practice,* 29**,** 259-270.

MORRISSEY, D. 2000. Proprioceptive shoulder taping. *Journal of Bodywork and Movement Therapies,* 4**,** 189-194.

MOSTAFAVIFAR, M., WERTZ, J. & BORCHERS, J. 2012. A systematic review of the effectiveness of kinesio taping for musculoskeletal injury. *Phys Sportsmed,* 40**,** 33-40.

MURAYAMA, K., CZARNIK-MATUSEWICZ, B., WU, Y., TSENKOVA, R. & OZAKI, Y. 2000. Comparison between conventional spectral analysis methods, chemometrics, and two-dimensional correlation spectroscopy in the analysis of near-infrared spectra of protein. *Applied Spectroscopy,* 54**,** 978-985.

MUYOR, J. M., ARRABAL-CAMPOS, F. M., MARTÍNEZ-APARICIO, C., SÁNCHEZ-CRESPO, A. & VILLA-PÉREZ, M. 2017. Test-retest reliability and validity of a motion capture (MOCAP) system for measuring thoracic and lumbar spinal curvatures and sacral inclination in the sagittal plane. *Journal of Back and Musculoskeletal Rehabilitation,* 30**,** 1319-1325.

NACHEMSON, A. L. 1981. Disc pressure measurements. *Spine,* 6**,** 93-97.

NELSON, N. L. 2016. Kinesio taping for chronic low back pain: A systematic review. *Journal of Bodywork and Movement Therapies,* 20**,** 672-681.

OPHIR, J., ALAM, S., GARRA, B., KALLEL, F., KONOFAGOU, E., KROUSKOP, T. & VARGHESE, T. 1999. Elastography: ultrasonic estimation and imaging of the elastic properties of tissues. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* 213**,** 203-233.

OSTELO, R. W. J. G. & DE VET, H. C. W. 2005. Clinically important outcomes in low back pain. *Best Practice & Research Clinical Rheumatology,* 19**,** 593-607.

PAMUK, U. & YUCESOY, C. A. 2015. MRI analyses show that kinesio taping affects much more than just the targeted superficial tissues and causes heterogeneous deformations within the whole limb. *Journal of Biomechanics,* 48**,** 4262-4270.

PAOLONI, M., BERNETTI, A., FRATOCCHI, G., MANGONE, M., PARRINELLO, L., COOPER, M. D., SESTO, L., DI SANTE, L. & SANTILLI, V. 2011. Kinesio Taping applied to lumbar muscles influences clinical and electromyographic characteristics in chronic low back pain patients. *European Journal of Physical and Rehabilitation Medicine,* 47**,** 237-244.

PARK, M.-C., KIM, E.-Y. & HA, M.-S. 2010. Effects of Taping Therapy by Methods on Back Pain and Muscle Flexibility of Bus Drivers's. *Journal of the Korea Academia-Industrial cooperation Society,* 11**,** 4367-4373.

PARKER, K. J., FU, D., GRACESWKI, S. M., YEUNG, F. & LEVINSON, S. F. 1998. Vibration sonoelastography and the detectability of lesions. *Ultrasound in Medicine and Biology,* 24**,** 1437-1447.

PARREIRA, P. D. C. S., COSTA, L. D. C. M., HESPANHOL JUNIOR, L. C., LOPES, A. D. & COSTA, L. O. P. 2014a. Current evidence does not support the use of Kinesio Taping in clinical practice: a systematic review. *Journal of Physiotherapy,* 60**,** 31-39.

PARREIRA, P. D. C. S., COSTA, L. D. C. M., TAKAHASHI, R., JUNIOR, L. C. H., JUNIOR, M. A. D. L., SILVA, T. M. D. & COSTA, L. O. P. 2014b. Kinesio Taping to generate skin convolutions is not better than sham taping for people with chronic non-specific low back pain: a randomised trial. *Journal of Physiotherapy,* 60**,** 90-96.

PENGEL, L. H., HERBERT, R. D., MAHER, C. G. & REFSHAUGE, K. M. 2003. Acute low back pain: systematic review of its prognosis. *BMJ,* 327**,** 323.

PILLAI, K. 1955. Some new test criteria in multivariate analysis. *The Annals of Mathematical Statistics***,** 117-121.

POLLARD, C. D., BRAUN, B. & HAMILL, J. 2006. Influence of gender, estrogen and exercise on anterior knee laxity. *Clinical Biomechanics,* 21**,** 1060-1066.

POURAHMADI, M. R., TAKAMJANI, I. E., JABERZADEH, S., SARRAFZADEH, J., SANJARI, M. A., BAGHERI, R. & TAGHIPOUR, M. 2017. Kinematics of the Spine During Sit-to-Stand Using Motion Analysis Systems: A Systematic Review of Literature. *Journal of Sport Rehabilitation***,** 1-35.

PROCACCI, P. & MARESCA, M. 1999. Referred pain from somatic and visceral structures. *Current Review of Pain,* 3**,** 96-99.

PURCELL, S. B., SCHUCKMAN, B. E., DOCHERTY, C. L., SCHRADER, J. & POPPY, W. 2009. Differences in ankle range of motion before and after exercise in 2 tape conditions. *The American Journal of Sports Medicine,* 37**,** 383-389.

RICHARDS, J. 2008. *Biomechanics in Clinic and Research: An interactive teaching and learning course, Churchill Livingstone*, Elsevier.

RICHARDS, J. G. 1999. The measurement of human motion: a comparison of commercially available systems. *Human Movement Science,* 18**,** 589-602.

ROELOFS, P. D., DEYO, R. A., KOES, B. W., SCHOLTEN, R. J. & VAN TULDER, M. W. 2008. Non-steroidal anti-inflammatory drugs for low back pain. *The Cochrane Library*.

ROSENTHAL, R., COOPER, H. & HEDGES, L. 1994. *Parametric measures of effect size*.

RUBINSTEIN, S. M., TERWEE, C. B., ASSENDELFT, W. J., DE BOER, M. R. & VAN TULDER, M. W. 2012. Spinal manipulative therapy for acute low-back pain. *The Cochrane Library*.

SALVAT, I. S. & SALVAT, A. A. 2010. Efectos inmediatos del kinesio taping en la flexión lumbar. *Fisioterapia,* 32**,** 57-65.

SATO, K., KIKUCHI, S. & YONEZAWA, T. 1999. In vivo intradiscal pressure measurement in healthy individuals and in patients with ongoing back problems. *Spine,* 24**,** 2468.

SCHLEIP, R., KLINGLER, W. & LEHMANN-HORN, F. 2005. Active fascial contractility: Fascia may be able to contract in a smooth muscle-like manner and thereby influence musculoskeletal dynamics. *Medical Hypotheses,* 65**,** 273-277.

SCHLEIP, R., VLEEMING, A., LEHMANN-HORN, F. & KLINGLER, W. 2007. Letter to the editor concerning “a hypothesis of chronic back pain: Ligament subfailure injuries lead to muscle control dysfunction”(m. Panjabi). *European Spine Journal,* 16**,** 1733-1735.

SCONFIENZA, L. M., SILVESTRI, E., ORLANDI, D., FABBRO, E., FERRERO, G., MARTINI, C., SARDANELLI, F. & CIMMINO, M. A. 2013. Real-time sonoelastography of the plantar fascia: comparison between patients with plantar fasciitis and healthy control subjects. *Radiology,* 267**,** 195-200.

SHIINA, T., NITTA, N., UENO, E. & BAMBER, J. C. 2002. Real time tissue elasticity imaging using the combined autocorrelation method. *Journal of Medical Ultrasonics,* 29**,** 119-128.

SHINOHARA, M., SABRA, K., GENNISSON, J. L., FINK, M. & TANTER, M. 2010. Real-time visualization of muscle stiffness distribution with ultrasound shear wave imaging during muscle contraction. *Muscle and Nerve,* 42**,** 438-441.

SHIRI, R., SOLOVIEVA, S., HUSGAFVEL-PURSIAINEN, K., TAIMELA, S., SAARIKOSKI, L. A., HUUPPONEN, R., VIIKARI, J., RAITAKARI, O. T. & VIIKARI-JUNTURA, E. 2008. The Association between Obesity and the Prevalence of Low Back Pain in Young Adults The Cardiovascular Risk in Young Finns Study. *American Journal of Epidemiology,* 167**,** 1110-1119.

SIGAL, L., BALAN, A. O. & BLACK, M. J. 2010. Humaneva: Synchronized video and motion capture dataset and baseline algorithm for evaluation of articulated human motion. *International Journal of Computer Vision,* 87**,** 4-27.

SIHVONEN , R., PAAVOLA , M., MALMIVAARA , A., ITÄLÄ , A., JOUKAINEN , A., NURMI , H., KALSKE , J. & JÄRVINEN , T. L. N. 2013. Arthroscopic Partial Meniscectomy versus Sham Surgery for a Degenerative Meniscal Tear. *New England Journal of Medicine,* 369**,** 2515-2524.

SŁUPIK, A., DWORNIK, M., BIAŁOSZEWSKI, D. & ZYCH, E. 2007. Effect of Kinesio Taping on bioelectrical activity of vastus medialis muscle. Preliminary report. *Ortopedia, Traumatologia, Rehabilitacja,* 9**,** 644-651.

SNOOK, S. H., WEBSTER, B. S., MCGORRY, R. W., FOGLEMAN, M. T. & MCCANN, K. B. 1998. The reduction of chronic nonspecific low back pain through the control of early morning lumbar flexion: a randomized controlled trial. *Spine,* 23**,** 2601-2607.

SOLOMONOW, M., ZHOU, B.-H., BARATTA, R., LU, Y. & HARRIS, M. 1999. Biomechanics of increased exposure to lumbar injury caused by cyclic loading: Part 1. Loss of reflexive muscular stabilization. *Spine,* 24**,** 2426-2434.

STÄRKE, C., KOPF, S., PETERSEN, W. & BECKER, R. 2009. Meniscal repair. *Arthroscopy: The Journal of Arthroscopic & Related Surgery,* 25**,** 1033-1044.

STAUDENMANN, D., VAN DIEËN, J. H., STEGEMAN, D. F. & ENOKA, R. M. 2014. Increase in heterogeneity of biceps brachii activation during isometric submaximal fatiguing contractions: a multichannel surface EMG study. *J Neurophysiol,* 111**,** 984-90.

STEGEMAN, D., ZWARTS, M., ANDERS, C. & HASHIMOTO, T. 2000. Multi-channel surface EMG in clinical neurophysiology. *Supplements to Clinical Neurophysiology,* 53**,** 155-162.

STERLING, M., HODKINSON, E., PETTIFORD, C., SOUVLIS, T. & CURATOLO, M. 2008. Psychologic Factors Are Related to Some Sensory Pain Thresholds but Not Nociceptive Flexion Reflex Threshold in Chronic Whiplash. *The Clinical Journal of Pain,* 24**,** 124-130.

TESARZ, J., HOHEISEL, U., WIEDENHÖFER, B. & MENSE, S. 2011. Sensory innervation of the thoracolumbar fascia in rats and humans. *Neuroscience,* 194**,** 302-308.

THELEN, M. D., DAUBER, J. A. & STONEMAN, P. D. 2008. The clinical efficacy of kinesio tape for shoulder pain: a randomized, double-blinded, clinical trial. *Journal of Orthopaedic and Sports Physical Therapy,* 38**,** 389.

TU, S. J., WOLEDGE, R. C. & MORRISSEY, D. 2016. Does 'Kinesio tape'alter thoracolumbar fascia movement during lumbar flexion? An observational laboratory study. *Journal of Bodywork and Movement Therapies,* 20**,** 898-905.

TURAN, A., TUFAN, A., MERCAN, R., TEBER, M. A., TEZCAN, M. E., BITIK, B., GOKER, B. & HAZNEDAROĞLU, S. 2013. Real-time sonoelastography of Achilles tendon in patients with ankylosing spondylitis. *Skeletal Radiology,* 42**,** 1113-1118.

VAN TULDER, M., BECKER, A., BEKKERING, T., BREEN, A., GIL DEL REAL, M. T., HUTCHINSON, A., KOES, B., LAERUM, E. & MALMIVAARA, A. 2006. Chapter 3 European guidelines for the management of acute nonspecific low back pain in primary care. *European Spine Journal,* 15**,** s169-s191.

VAN TULDER, M., FURLAN, A., BOMBARDIER, C., BOUTER, L. & GROUP, E. B. O. T. C. C. B. R. 2003. Updated method guidelines for systematic reviews in the cochrane collaboration back review group. *Spine,* 28**,** 1290-1299.

VAN ZUIJLEN, P. P. M., RUURDA, J. J. B., VAN VEEN, H. A., VAN MARLE, J., VAN TRIER, A. J. M., GROENEVELT, F., KREIS, R. W. & MIDDELKOOP, E. 2003. Collagen morphology in human skin and scar tissue: no adaptations in response to mechanical loading at joints. *Burns,* 29**,** 423-431.

VARGAS BATISTA, C., RUARO, J. A., BOEING RUARO, M., DUBIELA, A., ILVAN KERPPERS, I., PACHECO TYSKI SUCKOW, P., DE ANDRADE MELO KNAUT, S. & FRÉZ, A. R. 2014. Uso da kinesio taping na dor lombar: revisão sistemática. *ConScientiae Saúde,* 13.

VICENZINO, B., BROOKSBANK, J., MINTO, J., OFFORD, S. & PAUNGMALI, A. 2003. Initial effects of elbow taping on pain-free grip strength and pressure pain threshold. *Journal of Orthopaedic & Sports Physical Therapy,* 33**,** 400-407.

VIDEMAN, T. & BATTIÉ, M. C. 2012. Commentary: Back pain epidemiology—the challenge of case definition and developing new ideas. *The Spine Journal,* 12**,** 71-72.

VIEIRA, T. M., MERLETTI, R. & MESIN, L. 2010. Automatic segmentation of surface EMG images: Improving the estimation of neuromuscular activity. *J Biomech,* 43**,** 2149-58.

VITHOULKA, I., BENEKA, A., MALLIOU, P., AGGELOUSIS, N., KARATSOLIS, K. & DIAMANTOPOULOS, K. 2010. The effects of Kinesio-Taping® on quadriceps strength during isokinetic exercise in healthy non athlete women. *Isokinetics and Exercise Science,* 18**,** 1-6.

VLEEMING, A., POOL-GOUDZWAARD, A. L., STOECKART, R., VAN WINGERDEN, J. P. & SNIJDERS, C. J. 1995. The posterior layer of the thoracolumbar fascia. Its function in load transfer from spine to legs. *Spine (Phila Pa 1976),* 20**,** 753-8.

VOGLAR, M. & SARABON, N. 2014. Kinesio taping in young healthy subjects does not affect postural reflex reactions and anticipatory postural adjustments of the trunk: a pilot study. *Journal of Sports Science and Medicine,* 13**,** 673.

VOS, T., FLAXMAN, A. D., NAGHAVI, M., LOZANO, R., MICHAUD, C., EZZATI, M., SHIBUYA, K., SALOMON, J. A., ABDALLA, S. & ABOYANS, V. 2012. Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The lancet,* 380**,** 2163-2196.

WAI, E. K., ROFFEY, D. M., BISHOP, P., KWON, B. K. & DAGENAIS, S. 2010. Causal assessment of occupational bending or twisting and low back pain: results of a systematic review. *The Spine Journal,* 10**,** 76-88.

WALKER, B. F. 2000. The prevalence of low back pain: a systematic review of the literature from 1966 to 1998. *Journal of Spinal Disorders & Techniques,* 13**,** 205-217.

WALKER, B. F., MULLER, R. & GRANT, W. D. 2004. Low back pain in Australian adults: prevalence and associated disability. *J Manipulative Physiol Ther,* 27**,** 238-44.

WATANABE, K., KOUZAKI, M. & MORITANI, T. 2014. Non-uniform surface electromyographic responses to change in joint angle within rectus femoris muscle. *Muscle Nerve,* 50**,** 794-802.

WATSON, P. J., BOOKER, C. K., MAIN, C. J. & CHEN, A. C. N. 1997. Surface electromyography in the identification of chronic low back pain patients: the development of the flexion relaxation ratio. *Clinical Biomechanics,* 12**,** 165-171.

WILKE, H. J., NEEF, P., CAIMI, M., HOOGLAND, T. & CLAES, L. E. 1999. New in vivo measurements of pressures in the intervertebral disc in daily life. *Spine,* 24**,** 755-762.

WILLARD, F., VLEEMING, A., SCHUENKE, M., DANNEELS, L. & SCHLEIP, R. 2012. The thoracolumbar fascia: anatomy, function and clinical considerations. *Journal of Anatomy,* 221**,** 507-536.

WILLIAMS, S., WHATMAN, C., HUME, P. A. & SHEERIN, K. 2012. Kinesio Taping in Treatment and Prevention of Sports Injuries A Meta-Analysis of the Evidence for its Effectiveness. *Sports Medicine,* 42**,** 153-164.

WINN, N., LALAM, R. & CASSAR-PULLICINO, V. 2016. Sonoelastography in the musculoskeletal system: Current role and future directions. *World Journal of Radiology,* 8**,** 868.

WU, C.-H., CHEN, W.-S. & WANG, T.-G. 2015. Elasticity of the coracohumeral ligament in patients with adhesive capsulitis of the shoulder. *Radiology,* 278**,** 458-464.

WU, G. & CAVANAGH, P. R. 1995. ISB recommendations for standardization in the reporting of kinematic data. *Journal of Biomechanics,* 28**,** 1257-1261.

WU, G., SIEGLER, S., ALLARD, P., KIRTLEY, C., LEARDINI, A., ROSENBAUM, D., WHITTLE, M., D'LIMA, D. D., CRISTOFOLINI, L., WITTE, H., SCHMID, O. & STOKES, I. 2002. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *Journal of Biomechanics,* 35**,** 543-548.

WU, G., VAN DER HELM, F. C. T., VEEGER, H. E. J., MAKHSOUS, M., VAN ROY, P., ANGLIN, C., NAGELS, J., KARDUNA, A. R., MCQUADE, K., WANG, X., WERNER, F. W. & BUCHHOLZ, B. 2005. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics,* 38**,** 981-992.

YIP, Y., HO, S. & CHAN, S. 2004. Identifying risk factors for low back pain (LBP) in Chinese middle-aged women: a case-control study. *Health Care for Women International,* 25**,** 358-369.

YOO, J. W., LEE, D. R., SIM, Y. J., YOU, J. H. & KIM, C. J. 2014. Effects of innovative virtual reality game and EMG biofeedback on neuromotor control in cerebral palsy. *Biomed Mater Eng,* 24**,** 3613-8.

YOSHIDA, A. & KAHANOV, L. 2007. The effect of kinesio taping on lower trunk range of motions. *Research in Sports Medicine,* 15**,** 103-112.

YOUSEFPOUR, K., SHOJAEDIN, S. S. & EGHLIDI, J. 2013. A study on the effect of pilates exercise, kinesio tape and combined method on pain and functional disability in non-specific chronic low back pain. *Annals of Biological Research,* 4**,** 143-149.

APPENDIX A – KEY MATLAB SCRIPTS

1. Video to matrix conversion programme

This programme is used to convert video files collected from the ultrasound machine to an image matrix and to retrieve additional information, such as frame rate and total frame numbers, from the video file.

Supported formats: .AVI .MP4 .WMV
Additional input: crop position, and if the image needs to be flipped.
Output: cine image (Mtx), number of frames (NF), frame rate

```
%% a function to convert AVI cine-ultrasound image into mat file.
% Edited by RCW and JST 10.12.2014

function [Mtx,NF,FrameRate]=mp42Mat(File, Pos, Flip)
VidObj=VideoReader(File);
NF=VidObj.NumberOfFrames;
FrameRate=VidObj.FrameRate;

if isempty(Pos)
    Frame=read(VidObj,10);
    figure;
    BWF=rgb2gray(Frame);
    imshow(BWF,[])
    [c, r] = ginput(2);
    Pos=round([c r]);
    hold on
    plot([c(1) c(1) c(2) c(2) c(1)], [r(1) r(2) r(2) r(1) r(1)],'y')
    drawnow
end
% decide Mtx output as uint8 / double format
  Mtx=uint8(zeros(Pos(2)-Pos(1)+1,Pos(4)-Pos(3)+1,NF));
%   Mtx=zeros(Pos(2)-Pos(1)+1,Pos(4)-Pos(3)+1,NF);
for f=1:NF
    Frame=read(VidObj,f);
    %disp(f)
    BWF=rgb2gray(Frame);
    Trim=BWF(Pos(1):Pos(2),Pos(3):Pos(4));
    if Flip
        Trim=fliplr(Trim);
    end
    Mtx(:,:,f)=Trim;
end
```

2. Image feature tracking programme

a. Core tracking function

This is a searching function using normalised cross-correlation. Input a larger matrix as a template, and smaller matrix as a target, the programme returns target location information relative to the centre of template.

Input: location of target and mother template
Output: target shift amounts (pixel distance from the centre of template)

```
%--------------------
% Core Track Function, output: shift
% developed by Prof RCW and JST
% last edited by Jack 14.1.15 14:00
%--------------------

function [Shift]=CoreTrack(Target, Box)

% Target is a small picture (2D), Box is a bigger picture. We search for
% Target in Box. Shift =[0 0] if Target is in the centre of Box. Shift is 2
% numbers which are row shift(y shift) then column shift (x shift).
% negative values of Shuft(1) means upward movt, and of Shift(2) means
% leftwards

CorMat=normxcorr2(Target, Box);
Ovp=round((size(CorMat)-size(Box))/2); % Ovp is the amount by which CorMat overlap
Box at each of 4 edges
CorMat([1:Ovp(1) end-Ovp(1)+1:end],:)=[];
CorMat(:,[1:Ovp(2) end-Ovp(2)+1:end])=[];% cut down so that only complete overlap of
Bax and Target is considered
[~, Imax] = max(CorMat(:));

[Rpeak, Cpeak] = ind2sub(size(CorMat),Imax);
Mid=(size(CorMat)+1)/2;

Shift=[Rpeak, Cpeak]-Mid;
```

b. Track one target in a cine loop

This function run *Core Track* in a loop for a video clip. Input a video matrix, target position, target size and searching size. The programme returns path coordinates of the target and error message if searching were not satisfied (target moved out of the view or correlation was too low) in a certain frame.

```
%--------------------
% Function to track one selected point,
% output: moving path
% developed by Prof RCW and JST
% last edited by Jack 14.1.15 14:00
%--------------------
function [Path, Msg]= TrackOne(MovBit, TargPos, TargSize, BoxSize)
% tangPos contains 2 elements, the row and column of the top left corner of Target
Path=[]; Msg=[];
[RR, CC, FF]=size(MovBit);
Ovp=((BoxSize-TargSize)/2);
% Ovp is the amount by which Box overlap Target at each of 4 edges
CumShift=[0 0];
for Fr=1:FF-1
    Rstart=TargPos(1);
    Rend=TargPos(1)+TargSize(1)-1;
    Cstart=TargPos(2);
    Cend=TargPos(2)+TargSize(2)-1;
    OffLim=Rstart-Ovp(1)<1 || Rend+Ovp(1)>RR || Cstart-Ovp(2)<1 || Cend+Ovp(2)>CC;
    if OffLim;
        Msg=(['Off Limits after '  int2str(Fr-1) ' frames. Position :'
int2str([Rstart-Ovp(1) Rend+Ovp(1) Cstart-Ovp(2) Cend+Ovp(2)])]);
        Path(Fr,:)=[NaN NaN]; return;
    end
    Target=MovBit(Rstart:Rend,Cstart:Cend,Fr);
    Box=MovBit(Rstart-Ovp(1):Rend+Ovp(1),Cstart-Ovp(2):Cend+Ovp(2),Fr+1);
    Shift=CoreTrack(Target, Box);
    CumShift=CumShift+Shift;
    Path(Fr,:)=CumShift;
    TargPos=TargPos + Shift;
end
```

c. Track multiple targets in a cine loop

This function run *Track One* in a loop for a video clip. This function was used to track 60 targets within one tissue layer in one go. Input a video matrix, layer position and thickness. The programme returns the original coordinates of 60 targets and coordinate routes of the targets.

```
function [TargRoutes,TargPoints]= TrackLayer(MovBit, LayerPos, LayerSize)
%--------------------
% Track multi-points in one layer using function:
% Path= TrackOne(MovBit, TargPos, TargSize, BoxSize)
%
% developed by Prof RCW and JST
% last edited by Jack 20.1.15 15:35
%--------------------

% define TargPos and repeat TrackOne in the loop
NLR=6;
for LyrR=1:NLR
    for LyrC=1:10
        TargPos = LayerPos+[(LyrR-1)*LayerSize(1)
                  /NLR(LyrC-1)* LayerSize (2) / 11];
        TargPos=round(TargPos);
        TargSize = [ceil(LayerSize(1)/NLR) ceil(LayerSize(2)/10)];
        TargSize=round(TargSize);
        BoxSize = TargSize+6;

        [Path, Msg]= TrackOne(MovBit, TargPos, TargSize, BoxSize);
        if ~isempty(Msg); disp([' At ' int2str([LyrR LyrC]) ' ' Msg]); end
        TargPoints(LyrR,LyrC)={[TargPos(1)+TargSize(1)/2,TargPos(2)+TargSize(2)/2]};

TargRoutes(LyrR,LyrC)={[Path(:,1)+TargPos(1)+TargSize(1)/2,Path(:,2)+TargPos(2)+TargS
ize(2)/2]}; %data is stored as R C = Y X
    end
end
```

d. Master video tracking script

This function displays the first frame of a video clop, and allow user to define layers. The programme then calls all tracking function above. To track tissue movements by layers. The programme returns initial searching locations and the tracking results (stored by layers).

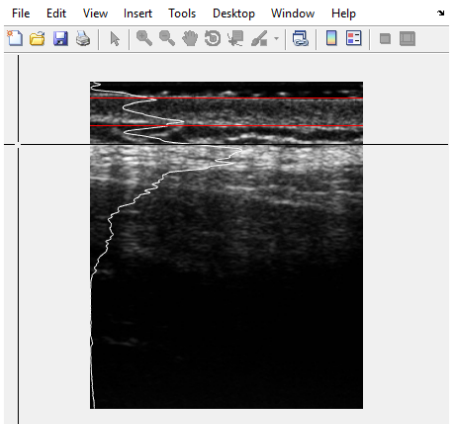


Figure. Example of tissue layer identification

```
function [Heaps, TargPts]=V2_3(Mtx,FTU,Bit,LR)
%==========
% Based on V2.mat, use FileList to nominate file and collect data across
% subjects. result is saved as
%   file_BF.mat (Bend forward) or file_RT.mat (Return)
% Jack, 18.08.2017 -@ for Ch6 analysis
%==========

[~, CC, ~] =size(Mtx);
if Bit==1
    MovBit=Mtx(:,:,FTU(1):FTU(2)); % take the first part of movie
else
    MovBit=Mtx(:,:,FTU(2):FTU(3)); % take the second part of movie
end
% the user define layers: 5 clicks on the picture
figure; imshow(MovBit(:,:,1),[]); hold on; axis ij
Bright= squeeze(mean(MovBit(:,:,1),2));
plot(Bright,1:length(Bright),'w')

for lay=1:5
    [~, LR(lay)]=ginput(1);
    LR(lay)=round(LR(lay));
    plot(xlim, [1 1]*LR(lay), 'r')
    drawnow
end

%% Tracking each layer using TrackLayer function.
for lay=1:4
    LayerPos=[LR(lay)  round(CC/4)];
    LayerSize=[LR(lay+1)-LR(lay) round(CC/2)];
    [Heap,TargPt] = TrackLayer(MovBit, LayerPos, LayerSize);
    Heaps(lay)={Heap};
    TargPts(lay)={TargPt};
end
```

3. TMSi EMG conversion programme (GUI programme)

This is a GUI programme design converts TMSI files (.S00, .S01) to .mat files to fullfil needs of the present PhD. The core conversion function (tmsi_convert.mat) was provided by TMSi.

Operation steps:

- user browse or paste path contains subject folders
- Choose subject folder from list
- Choose one tmsi file(.S00) from list (programme will check if .S01 exist)
- Enter Channel number of trigger
- push 'View Signals' button to display signals. Signals are converted into MATLAB format in this step.
- push 'Save .mat file' button to generate mat file if the signals are satisfied.

```
%% CONVERT_TMSI a MATLAB GUI code for .S00 file Conversion
% This is a GUI programme converts TMSI files (.S00, .S01) to .mat files.
% Core conversion function - tmsi_convert.mat is provided by TMSi
%
% Last Modified by Jack v 2.0 25-Apr-2015 17:45

% Begin initialization code - DO NOT EDIT
function varargout = Convert_TMSI(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @Convert_TMSI_OpeningFcn, ...
                   'gui_OutputFcn',  @Convert_TMSI_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end
if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
%**************************************************************************
% --- OPENING
%**************************************************************************
function Convert_TMSI_OpeningFcn(hObject, ~, handles, varargin)
handles.output = hObject;
guidata(hObject, handles);

function varargout = Convert_TMSI_OutputFcn(hObject, ~, handles)
varargout{1} = handles.output;

function figure1_ResizeFcn(hObject, ~, handles)


%**************************************************************************
% --- tmsiPath.. executes when dir is changed or at startup
%**************************************************************************
function tmsiPath_Callback(hObject, ~, handles)
pathname = char(get(handles.tmsiPath, 'String'));
DS=dir([pathname '\*.']);
Names={DS.name}';
SubDirNames=Names;
set(handles.TMSI_Dir,'String',SubDirNames)
```

```
%*************************************************************************
% --- Executes on button press in BrowseButton.
%*************************************************************************
function LoadButton_Callback(hObject, ~, handles)
pathname = uigetdir('Locate the folder where TMSI files is');
DS=dir([pathname '\*.']);
Names={DS.name}';
SubDirNames=Names;
set(handles.tmsiPath, 'String', pathname);
set(handles.TMSI_Dir,'String',SubDirNames)

%*************************************************************************
% --- TMSI_Dir. Executes on folder selection.
%*************************************************************************
function TMSI_Dir_Callback(hObject, ~, handles)
selectno = get(handles.TMSI_Dir,'Value');   % find out which one is selected
list=get(handles.TMSI_Dir,'String');        % get the  list
Directory=char(list(selectno));               % get the name of the selected
directory
RootDir=char(get(handles.tmsiPath,'String'));   % get the name of the Root directory
path=[RootDir, '\', Directory, '\'];          % make the path string
handles.filepath=path;                        % save the path string
dir_struct = dir([path, '*.S00']);            % get the directory details
Names={dir_struct.name}';
set(handles.Files,'Value',1)
set(handles.Files, 'String',Names)
guidata(hObject,handles)

%*************************************************************************
% --- ConvertButton. Executes on button press in hit
%*************************************************************************
function ConvertButton_Callback(hObject, ~, handles)
% selectno = get(handles.TMSI_Dir,'Value');   % find out which one is selected
% list=get(handles.TMSI_Dir,'String');        % get the  list
% Directory=char(list(selectno));               % get the name of the selected
directory
% RootDir=char(get(handles.tmsiPath,'String'));   % get the name of the Root
directory
% pathname=[RootDir, '\', Directory, '\'];
selectno = get(handles.Files,'Value');             % find out which one is selected
list=get(handles.Files,'String');                   % get the  list
filename=list{selectno}; % .S00 file
file2=[list{selectno}(1:end-1) '1'];
pathname=handles.filepath;
SecFile=dir([pathname file2]);
TriN = str2num(get(handles.TriNumber,'String'));
if isempty(SecFile)
    [trimEMG,OriEMG,trimTime,OriTime]= Onefile(pathname,filename,TriN);
    handles.trimEMG=trimEMG;
    handles.trimTime=trimTime;
    handles.OriEMG=OriEMG;
    handles.OriTime=OriTime;
    handles.axes1.YTick=[1:1:17];
else
    [trimEMG,OriEMG,trimTime,OriTime]=TwoFiles(pathname,filename,file2,TriN);
    handles.trimEMG=trimEMG;
    handles.trimTime=trimTime;
    handles.OriEMG=OriEMG;
    handles.OriTime=OriTime;
    handles.axes1.YTick=[1:1:17];
end
    matfile=regexprep(filename, '.S00', '.mat','ignorecase');
    handles.NFile = [pathname matfile];
    guidata(hObject,handles);
```

```
% -- One TMSI file conversion core function --
function [trimEMG,OriEMG,trimTime,OriTime]=Onefile(pathname,filename,TriN)
    TM = tmsi_convert(pathname,filename);
    cla
    trigger=TM.data(Mannion et al.)(1000:end);
    SP=find(abs(trigger)>0.2, 1, 'first');
    EP=find(abs(trigger)>0.2, 1, 'last');
    trimTime=((SP:EP)-SP)/2048;
    OriTime=((1:length(trigger))-SP)/2048;% set trigger as 0s
        for c=1:length(TM.data)
        yy=TM.data{c}(1000:end);
        OriEMG(:,c)=yy;
        plot(OriTime, (yy+c*1000)/1000)
        hold on
        end
        axis ij
        ylim([0 c+1])
        ylabel('Channel #')
        xlim(round([OriTime(1) OriTime(end)]))
      plot([1 1]*OriTime(SP),ylim,'r' )
      plot([1 1]*OriTime(EP),ylim,'r' )
      for ref=1:round(c/8)
      plot (xlim,[8*ref+0.5 8*ref+0.5],'k-')
      end
    trimEMG=OriEMG(SP:EP,:);

% -- two tmsi files core function --
 function [trimEMG,OriEMG,trimTime,OriTime]=TwoFiles(TmsiPath,File1,File2,TriN)
% Convert two tims file to matlab
signals1=tmsi_convert(TmsiPath,File1);
signals2=tmsi_convert(TmsiPath,File2);

% check the length of two TMSI files
L1=length(signals1.data{3});
L2=length(signals2.data{3});
LL=L1-L2;
% trim the longer file
if LL>=0
    for i=1:TriN-1
        EMG(:,i)=signals1.data{j}(1000:end-LL);% first 1000 points removed
        EMG(:,i+TriN-1)=signals2.data{i}(1000:end);
        EMG(:,TriN*2-1)=signals2.data(Mannion et al.)(1000:end); % put trigger in
CH65
        % if ERROR occur check which file contains trigger
    end %of i loop
else if LL<0
        for i=1:TriN-1
            EMG(:,i)=signals1.data{i}(1000:end);% first 1000 points removed
            EMG(:,i+TriN-1)=signals2.data{i}(1000:end-LL);
            EMG(:,TriN*2-1)=signals2.data{33}(1000:end-LL);% put trigger in CH65
        end % of i loop
    end % of else if
end % of if
    SP=find(abs(EMG(:,TriN*2-1))>0.2, 1, 'first');
    EP=find(abs(EMG(:,TriN*2-1))>0.2, 1, 'last');
    trimTime=((SP:EP)-SP)/2048;
    OriTime=((1:length(EMG))-SP)/2048;% set trigger as 0s
    cla
    for c=1:(TriN-1)*2
        plot(OriTime, (EMG(:,c)+c*1000)/1000)
        hold on
    end
        ylim([0 (c+1)])
        axis ij
        ylabel('Channel #')
        xlim(round([OriTime(1) OriTime(end)]))
      plot([1 1]*OriTime(SP),ylim,'r' )
      plot([1 1]*OriTime(EP),ylim,'r' )
      for ref=1:round(c/8)
      plot (xlim,[8*ref+0.5 8*ref+0.5],'c-')
      end
    trimEMG=EMG(SP:EP,:);
    OriEMG=EMG;
```

```
%**************************************************************************
% ---SAVE function
%**************************************************************************
function SaveButton_Callback(hObject, eventdata, handles)

NFile=handles.NFile;
trimEMG=handles.trimEMG;
trimTime=handles.trimTime;
OriEMG=handles.OriEMG;
OriTime=handles.OriTime;
save(NFile, 'trimEMG','OriEMG','trimTime','OriTime')

path=handles.filepath;
dir_struct = dir([path, '*.mat']);
Names={dir_struct.name}';
set(handles.Matfiles,'Value',1)
set(handles.Matfiles, 'String',Names)
guidata(hObject,handles)


%**************************************************************************
% UNUSED CALLBACKS DUMPED HERE
%**************************************************************************
function TriNumber_Callback(hObject, eventdata, handles)
function Matfiles_Callback(hObject, eventdata, handles)
%**************************************************************************
% --- Files
%**************************************************************************
function Files_Callback(hObject, ~, handles)


%**************************************************************************
% --- CREATE FUNCTIONS DUMPED HERE.
%**************************************************************************
function tmsiPath_CreateFcn(hObject, ~, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function Files_CreateFcn(hObject, ~, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function TMSI_Dir_CreateFcn(hObject, ~, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function TriNumber_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function MatFile_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function figure1_CreateFcn(hObject, eventdata, handles)
function Matfiles_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes during object creation, after setting all properties.
function axes1_CreateFcn(hObject, eventdata, handles)
function axes1_ButtonDownFcn(hObject, eventdata, handles)
```

4. EMG processing programmes

a. Notch filter

This is function cuts off a specific band of frequency from a time-series data such as EMG. Input 1-d signal, cut-off frequency and sampling frequency, the programme returns a matrix contains filtered data.

```
%% Notch filter
% input DirtyData = dirty data,
%       cutoo = target cutting frequency,
%       fs= sampling rate
%
% Jack 07.05.2015 19:29

function [FiltData]=NotchFilter(DirtyData,cutoff,Fs)
            Time=((1:length(DirtyData))-1)/Fs;
            Raw=timeseries(DirtyData,Time);
            Ints=[cutoff-2 cutoff+2]; % the frequency intervals, in hertz, for
filtering the data:
            Filt = idealfilter(Raw,Ints,'notch');
            FiltData=Filt;
```

b. Band-pass filter

This is function allows a specific band of frequency from a time-series data such as EMG to pass. Input 1-d signal, pass frequency range and sampling frequency, the programme returns a matrix contains filtered data.

```
%% Band-Pass filter
% input DirtyData = dirty data,
%       pass = target cutting frequency,
%       fs= sampling rate
%
% Jack 07.05.2015 19:40

function [FiltData]=PassFilter(DirtyData,pass,Fs)

            Time=((1:length(DirtyData))-1)/Fs;
            Raw=timeseries(DirtyData,Time);
            Ints=pass; % the frequency intervals, in hertz, for filtering the data:
            Filt = idealfilter(Raw,Ints,'pass');
            FiltData=Filt
```

c. EMG processing for amplitude analysis

This is a master script to process one EMG file which contains 16 channels of data. The first half cleans the signals with a 50 Hz notch filter and a 20 – 500 Hz band pass filter. The second half performs entire-wave rectification followed by a smoothing process using a fourth order butterfly filter with a 50Hz windowsize.

```
%% EMG processing
% dfile= 'D:\Data\KT-3data\EMG\JKT302\NTR2.mat';load(dfile)

function []=Pro01_1(dfile)
load(dfile)
%% clean EMG signals
for j = 1:16
         %Pull out current EMG channel
         curData = trimEMG(:,j);
         %Run through EMG via notch filter to remove electrical noise
         [notchedData]=NotchFilter(curData,50,2048);
         %Run notched data through pass filter to remove noise
         [allFilteredData]=PassFilter(notchedData,[20 500],2048);
         %Place in new array
         cleanedEMGData(:,j) = allFilteredData;
end

%% processing
% filter preparation for smoothing
 emgFs =2048;
 fnyq=emgFs/2;
 [b,a]=butter(4,20*1.116/fnyq,'low'); % 4th order;50Hz %20*1.116/fnyq
% preparation finished

for j = 1:16 %ch
         %Pull out current EMG
         curEMG = cleanedEMGData(:,j);
         %Rectify the EMG
         curRectEMG = abs(curEMG - nanmean(curEMG));
         %Smooth the EMG
         smEMG=filtfilt(b,a,curRectEMG);
         smoothedEMGData(:,j)=smEMG;
end
save(dfile,'cleanedEMGData','smoothedEMGData','-append')
```

d. EMG frequency analysis (FFT transfer)

This function performs fast Fourier transform (FFT) for EMG data. Input 1-d matrix data and sampling frequency, and the programme returns a power spectrum and mean power frequency according to the spectral density.

```
function [MPF]=emgFFT(y,Fs)

T = 1/Fs;                     % Sample time
L = length(y);                % Length of signal
t = (0:L-1)*T;                % Time vector

% figure
% plot(t,y)
%% #21 FFT and Power spectrum
NFFT = 2^nextpow2(L);         % Next power of 2 from length of y
Y = fft(y,NFFT)/L;
f = Fs/2*linspace(0,1,NFFT/2);

% Plot single-sided amplitude spectrum.
figure
plot(f,2*abs(Y(1:NFFT/2)))
MPF =  f*s/sum(s);
```

APPENDIX B – ETHICAL APPROVALS

Shihfan Jack Tu

From: Dylan Morrissey
Sent: 08 April 2015 16:56
To: Shihfan Jack Tu
Cc: Hazel Covill
Subject: amended ethics
Attachments: Ethics_updated080415 DM.docx; InformationSheet_SJT_updated April 2015.docx

Dear Jack,
Thank you for the amended ethics form, which I can approve as an amendment to QMREC2014/24/3 . This should allow you to look at more than one movement. You will still need a letter from any additional recruitment site, and remember none of these can be NHS.
Best wishes
Dylan

Thanks for follow @DrDylanM

Dr Dylan Morrissey
NIHR/HEE Consultant Physiotherapist and Clinical Reader
Centre for Sports and Exercise Medicine
William Harvey Research Institute
Bart's and the London School of Medicine and Dentistry
Queen Mary University of London

a: Mile End Hospital, Bancroft road, London E1 4DG
t: +447941710273
e: d.morrissey@qmul.ac.uk

Shihfan Jack Tu

From: Dylan Morrissey
Sent: 27 January 2016 13:04
To: Shihfan Jack Tu; Hazel Covill
Subject: QMREC2014/24/57 Adam Lucas / Jack Tu The effect of different tensions of K-taping in vivo thoracolumbar tissues movement – an observational study
Attachments: 150806060 Research Proposal DM.docx; AL_info_consent DM.docx

QMREC2014/24/57 Adam Lucas / Jack Tu The effect of different tensions of K-taping in vivo thoracolumbar tissues movement – an observational study

Dear Jack and Adam,
Thank you for re-submitting this after the meeting – it is now approved as QMREC2014/24/57.

Hazel - fyi

Best wishes
Dylan

thanks for follow @DrDylanM

TEAM (TreatmentEffectsAndMechanisms) Research group

Next scientific meeting Muscles and Movement April 22nd 2016

Video about our MSc educational programme

Dr Dylan Morrissey
NIHR/HEE Consultant Physiotherapist and Clinical Reader
Centre for Sports and Exercise Medicine
William Harvey Research Institute
Bart's and the London School of Medicine and Dentistry
Queen Mary University of London

a: Mile End Hospital, Bancroft road, London E1 4DG
t: +44 (0)7941710273

Recruitment poster

Barts and The London
School of Medicine and Dentistry

Kinesio Taping

KT is a non-invasive treatment, which is suggested to be used as an additional treatment to usual care – it involves putting some elastic strips on the skin to provide stimulation to trigger its proposed effects.

This technique was used in athletes for supporting rehabilitation and performance and is now widely used for treating different conditions.

Please contact

Jack Tu
Centre for Sports and Exercise Medicine
Queen Mary University of London
Tel: 020 7782 6073
Email: s.j.tu@qmul.ac.uk
Project Supervisor: Dr Dylan Morrissey

Suffering from

Back Pain?

We are currently researching the positive effects and mechanism of Kinesio Taping on low back pain as it is an unclear and troublesome condition affecting our work and daily life.

The aim of this study is to examine the biomechanical response of human tissues to Kinesio Taping treatment in order to uncover the processes underlying low back pain and enhance the knowledge relating to Kinesio Taping.

We would like to recruit participants with and without low back pain to take part in an on-going study so that we can better understand how Kinesio Taping works. This may lead to better or more suitable treatments being available in the future.

The study will involve a minimum of two visits (one hour) to Queen Mary, University of London. Kinesio Taping is available for participants, performed by qualified practitioner.

Please contact Jack Tu if you are interested in taking part or finding more out about the current study.

Participant information Sheet

Barts and The London School of Medicine and Dentistry

Sport and Exercise Medicine
Bart's and the London School of Medicine and Dentistry
Mann Ward
Mile End Hospital
Bancroft Road
London E1 4DG
Telephone: +44 (0)20 8223 8839
http://www.smd.qmul.ac.uk/sportsmed

Title

Immediate effects and mechanisms of kinesio taping for people with low back pain

REC Protocol Number: **QMREC2014/24/3**

Participant Information Sheet

We would like to invite you to participate in this research project. Choosing not to take part will not disadvantage you in any way, nor affect your access to treatment or services. Before you decide, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Aim of the project

The aim of this project is to better understand the effects of taping the lower back of people who do, or do not, have back pain.

Background information

Researchers have studied the causes of back pain for many years. The joints in the spine are known to play a part, however more recent research has shown that other tissues may also be important. For example, the stuff that joins muscles and bones together, which is known as connective tissue or fascia, changes over time and these changes may lead to pain in some

people. Some other research has shown that taping might help back pain but how it works is not clear. The aim of this project is to find out more about these aspects.

What does the project involve?

We want to measure the movements of people who suffer or have suffered from back pain, and those that do not. This is why you are being asked to take part. We're going to scan the muscles of the lower back by using ultrasound, as well as measure your back movement. We will do this before and after applciaiotn of 'Kinesio Taping'. Kinesio tape is a term of elastic tape commonly used clinically for assisting with rehabilitation.

What do I have to do?

If you volunteer to take part you will be invited to meet the study team at the Human Performance Laboratory, Queen Mary's University of London on one occasion. The visit will take 90 minutes.

- After answering any questions you may have, you will be asked to fill in a questionnaire. The first part will ask for you for personal details such as age, sporting activities past and present and amount of playing time. The second part will deal with self-reported injury, particularly pain or injury in the back and hip area if applicable.
- A member of the research team will measure your height, weight and waist circumference.
- A short physical examination will be undertaken to determine your suitability to participate.
- You will be required to wear clothing that reveals the skin of the lumbar spine, shoulder blades and legs. A pair of close fitting shorts would be ideal. We can provide these if necessary. (Female participants need to bring and wear a sports bra or vest)
- We will then attach several electrodes on your back to measure the electrical activity in your muscles.
- Then we need to attach 18 small infra-red motion sensors to your trunk and legs with medical grade double side sticky tape.
- During data collection process, an ultrasound probe will be used in scanning your back. A water-based gel will be used to help the scanner move about.
- We will then make some measurements of your movement patterns during several movement tasks while standing and forward bending. You will be asked to perform the movement in different conditions such as holding a small weight or supporting yourself with your hands.
- You will receive Kinesio-taping during the experiment after which we will ask you to repeat the same simple movements.

It is important to note that no diagnosis will be made, or treatment given but you may find the kinesio-taping helpful - in which case we will leave it on.

Who can be included in this project?

- If you are over 18 years of age, both men and women.
- If you have no lower back pain
- If you currently have, or have had lower back pain in the last 12 months
    - Low back pain that has been recurrent over a period of time, and has been problematic for you in the last week OR
    - Acute low back pain with recent onset or exacerbation in the last two weeks

Who cannot take part?

- If you have a skin infection or broken skin on the back, you will have to wait 2 weeks after it heals before taking part
- If you have had a previous severe back or leg injury, or surgery on your back
- If you have a spinal deformity, ankylosing spondylitis, or rheumatoid arthritis in any part of your body
- If you ever had a spinal fracture, a tumour in your back, or an infection around your spine
- If you ever had nerve root compression or spinal disc damage
- If you have cancer
- If you have a bleeding disorder, for example, haemophilia. Or if you take Warfarin or similar blood thinning medication
- If you take corticosteroid medication, e.g. Prednisolone. Or high doses of inhaled steroids. Or if you have injections in your lower back
- If you are pregnant, or are planning pregnancy

Are there any risks?

- Ultrasound is a safe non-invasive method to take pictures. It consists of low frequency sound waves, which create a picture, it poses no harm. This is the same technology used to scan unborn babies and many other areas of medicine as well.
- The EMG electrodes do not carry any electricity into your body. These electrodes are self-adhesive and designed to stick to skin and be removed easily and painlessly.
- The Kinematic measure is using cameras to record your movement. Cameras used in this project are infra-red cameras so do not record images just position.
- You will not be exposed to any harmful radiation.

If I decide to take part in the project, can I change my mind?

- Yes, you can change your mind and withdraw from the project, without providing a reason, at any time.

How does taking part affect my usual health or back care?

- You can have any treatment or care you have for your back. Continue to take any medication as normal. Taking part in this project will not affect your normal care; you can continue visits to your doctor, or any other healthcare practitioner.

Will I know the results of this project?

- We can send you a summary of the results when the study is completed. If you wish to receive this, please indicate this on the consent form.

Will the information be confidential?

- If you participate in this study you will be given an identification number and so will remain completely anonymous throughout. All personal information linking you to this number will be kept separately and stored securely on a database server to which only the research team will have access to. All information will be handled in accordance with the provisions of the data protection act 1998 and your confidentiality assured.

How can I take part?

If you would like to take part, either:

- email the researcher Shihfan Jack Tu at s.j.tu@qmul.ac.uk, please include your name and contact phone number
- or call Jack on 020 7882 6073 / 07732 400 420

A member of the research team will contact you to arrange a suitable time for the test and ultrasound scan.

Who is in the research team?

Researcher: Shihfan Jack Tu

Jack is a PhD student in Centre for Sports and Exercise Medicine, Queen Mary University of London. Jack has worked as a sports therapist / athletic trainer for 6 years. He is particularly interested in Taping in a wide range of conditions. This project is part of his PhD research, investigating changes in connective tissue, muscle activity and bio-mechanic in people after taping.

PhD Supervisor: Dr Dylan Morrissey

Dr Morrissey is senior clinical lecturer & consultant physiotherapist in Centre for Sports and Exercise Medicine at Queen Mary University of London. He is Jack's PhD study supervisor.

This study has been approved under the generic human performance lab ethical clearance. QMUL Research Ethics Committee Protocol Number is **QMREC2014/24/3.**

Sources of information about back pain:

NHS website:

http://www.nhs.uk/conditions/back-pain/Pages/Introduction.aspx

BackCare, a charity for people with back pain

http://www.backcare.org.uk

Contacts:

Correspondence details of the main researcher are following. If you are unsure about eligibility or have further questions regarding this project should you feel free to contact to obtain further details.

Shihfan Jack Tu
Centre for Sport and Exercise Medicine
Mile End Hospital
Bancroft Road
LONDON E1 4DG
s.j.tu@qmul.ac.uk
020 7882 6073 / 07732400420

Alternatively, you can contact the project supervisor:

Dr Dylan Morrissey
Centre for Sport and Exercise Medicine
Mile End Hospital
Bancroft Road
LONDON E1 4DG
d.morrissey@qmul.ac.uk
02082238839

or Research Ethics Committee, Queen Mary, University of London

Hazel Covill
Room W117, Finance Department
Queens' Building
Queen Mary University of London
Mile End Road
London E1 4NS
h.covill@qmul.ac.uk
020 7882 7915 (not Fridays)

Participant consent form

Queen Mary University of London

Barts and The London School of Medicine and Dentistry

Consent form

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: The effect and mechanisms of Kinesio taping on thoracolumbar fascia gliding: a snapshot observational study of patients with non-specific low back pain

Thank you for considering taking part in this research. Please read the statements below and initial the boxes if you are happy to proceed:

Please initial box

1. I confirm that I have read the Participant Information sheet for the above study. I have had the opportunity to consider the information and ask questions which have been satisfactorily answered. ☐
2. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time. ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without any consequences to my care or legal rights. ☐
4. I consent to the processing of my personal information for the purposes of this research study. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998. ☐
5. I agree to take part in the above named study ☐

[redacted]

Name of Participant	Date	Signature

[redacted]

Name of individual taking consent	Date	Signature

Ethical approval application form

For Office Use Only:
Rec Reference ……
Date received: ……

Queen Mary University of London

Application form – Queen Mary Research Ethics Committee

1 Name and email address of applicant
Mr Shihfan Jack Tu MSc BSc Centre for Sports and Exercise Medicine, WHRI Email : s.j.tu@qmul.ac.uk
2 Title of study
Immediate Effect and Mechanism of Kinesio Taping on Lower Back
3 Investigators
Mr Shihfan Jack Tu MSc BSc

Dr Dylan Morrissey PhD MSc MMACP MCSP Professor Roger Woledge, Professor Emeritus of Experimental Physiology
4 Proposed timetable
Preferred start date: March 2014 Projected date of completion: Dec 2015
5 Other organisations involved
N/A
6 Other REC approval
N/A
7 Nature of project e.g. undergraduate, postgraduate
This is a postgraduate research project which will build the first part of a PhD study.
8 Purpose of the research
The purpose of the study is to investigate fascia movement, muscle activation and kinematics during simple movement tests which are commonly used in the assessment of subjects with low back pain and to determine whether any systematic differences in fascia and muscle between taping and non-taping trials.
9 Study design, methodology and data analysis
Each potential participant will be provided with a consent form, information sheet and an explanation of the procedure before participating in the study.

Each subject will be asked to complete a written screening questionnaire to define their lower back, pelvic and low limb injury status that has impacted on their ability to work or perform general activities in the last twelve months. The questionnaire will comprise of two parts; characterisation of participants and self-reported injury history.

Characterisation includes:

Biological data - age, age at puberty, height, weight

It is at this point that consent will be taken and the questionnaire gone through with the subject. At this time, additional data will be collected on:

- Family history
- Past medical history
- Exercise load – past / current
- Injury – onset / presence of prodromic symptoms
- Pain area and behaviour

A physical examination will then be undertaken to determine appropriate inclusion criteria as well as other associated features that may identify subgroups in analysis of the data. This will include:

- Spinal range of motion and manual segmental examination

- Low back and hip joint range of motion tests

- neurological

- SLR and slump

- classification of dysfunction

- Body chart

Subjects will then undergo ultrasound back scanning using clinical ultrasound device (Voluson-I Rev. 3, GE Healthcare, Australia), motion analysis measurements using non-invasive 3-dimensional infra-red cameras (Codamotion

cx1, Charnwood Dynamics, Loughborough, UK) - using standard marker placement protocols for the spine, pelvis and lower limb. Electromyographic (EMG) readings will be taken from the erector spinae muscle using surface EMG device (Refa 72 system, TMSI, Netherlands).

Testing will take place in the Human Performance Laboratory at QMUL and should take no longer than 90 minute. Participants will be required to take the same assessment twice in different day.

Data analysis

Based on the results of the questionnaire and the physical examination, sub-groups will be defined according to the result of assessment. This project recruit a control group without low back pain which will be age, weight, height and physical activity matched.

Analysis of collected data for tracking fascial movement, muscle activity and kinematics will be done by using computer programmes written in MatLab (Mathworks, USA).

Statistical analysis

The data will be assessed for normality and appropriate group comparison analysis undertaken accordingly. The power of the study will be 80% with statistical significance set at $p < 0.05$.

10 Participants to be studied

Number of participants – approximately 21 in each group

Lower age limit – 18

Upper age limit – 70

Sample Size

According to the pilot study, effect size in this study is expected as 0.6 in this study. Desired significance level will be determined based on α = .05 and the desired level of power (1-β) is set as 80%. Sample size of 21 is required in each group at power level set above. However, the effect size will be computed as the data is collected. We have allowed for an extra 5 subjects in case of data loss, unexpected sub-groups and to detect smaller significant differences

11 Selection criteria

Low back pain group

Inclusion criteria

- 18 year of age or older
- Low back pain
    - Present on at least half the days in a 12-month period, or on less than half the days in a 12-month period occurring in multiple episodes over a year. OR
    - Low back pain had limited activities of daily living or training sessions OR
    - Acute low back pain with recent onset or exacerbation in the last two weeks

Exclusion criteria

- Previous severe back, lower abdominal, hip, groin region or low limb injury (or surgery on above area).
- Spinal deformity (such as scoliosis, kyphosis, stenosis and ankylosing spondylitis or rheumatoid arthritis in any part of the body)
- Spinal fracture
- Neurological disorder or bleeding disorders
- Injection at lower back or litigation for LBP and serious infection.
- The subject are taking corticosteroid medication (e.g. Prednisolone) or high doses of inhaled steroids
- Systemic disease
- Significant psychological condition

Control group

Inclusion criteria

- Over 18 years of age

Exclusion criteria

- History of low back pain in the past year
- Surgery to the lower abdominal, back or hip
- Neurological symptoms
- Systemic disease
- Significant psychological condition

.

12 Recruitment (including incentives and compensation)

Participants will be approached in several ways. Advertisements will be made in local papers, the university campus, local private practice and sports centres.

The advert will include details of the research project, its purpose, objective and that participants are required. The advert will reflect the affiliation with QMUL. This advert will be subject to consideration by Dr Morrissey prior to use.

No diagnosis will be made during data collection. However, if the subjects have concerns about their lower back, they will be referred to suitable health practitioners. Sources for further information about lower back pain will also be provided.

A contact telephone number will also be enclosed so that any questions or queries potential participants might have can be addressed through a follow up telephone interview with Dr Dylan Morrissey or Shihfan Jack Tu.

The assessments will all be undertaken at the HPL, QMUL. As an incentive, each participant will be offered an explanation of the findings. No financial or other reward will be given to participants.

13 Ethical considerations and risks to participants

In safety consideration of this study, ultrasound, EMG and motion capture are safe non-invasive method to collect bio-signals, pictures and videos. Participants will not be exposed to any harmful radiation. Ultrasound

consists of low frequency sound waves, which create a picture, it poses no harm.

It will be another consideration that privacy in the data collection areas will be maximised. Subjects will be encouraged to bring suitable clothing. Male subjects need to remove sufficient clothing and wear shorts and female participants need to wear sports bra / vest and shorts to attach the motion markers and the ultrasound probe to the legs and torso. In order for the EMG electrode pads to be well adhered, small areas of the skin will need to be shaved and cleaned. Kinesio tapes, electrode stickers and ultrasound gel will be applied some people might have skin allergy to sticky stuffs, however allergy test will be done befor data collection.

Investigator will explain all procedures to each participant; they will understand that this study will not cause any injury. All data collection will be performed with the subjects' informed consent. Participant Information Sheets including detail information will be given to the participants before. Consent Forms will be filled and signed by each participant before the survey.

Each participant will be protected from harm or injury with all measurements being undertaken in a controlled manner; and they can change their mind and withdraw from the project, without providing a reason, at any time. If any abnormal sing is found in the ultrasound scanning, the researcher will to refer the subjects to suitable health practitioners and also provide sources for further information about lower back pain in the Participant Information Sheet.

If participants feel back pain is increased after receiving Kinesio Taping, data collection will be ceased and all tapes will be removed immediately; then the subject will be refer to suitable practitioners.

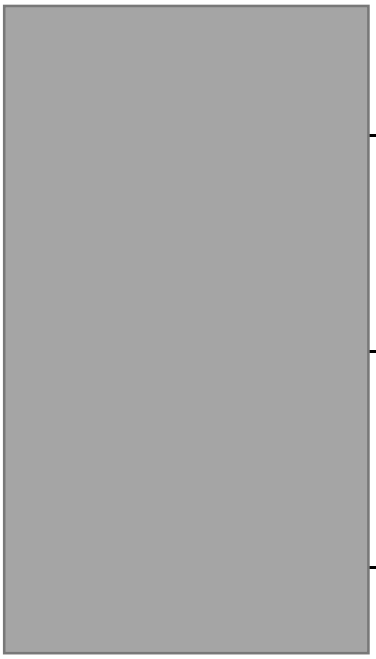
14 Confidentiality, anonymity, and data storage

All data will be kept in accordance with the Data Protection Act 1998. Each participant's confidentiality and privacy will be assured by the use of a code which will be characterized by each participant's initials and the date of the test.

All collected data will be coded; no names will appear on the images. Each participant will be allocated their code on consenting to the study and each coded participant will also have the date that the assessment will be undertaken to ensure participants' privacy. No names or any other personal identification will be shown while publishing result of the study.

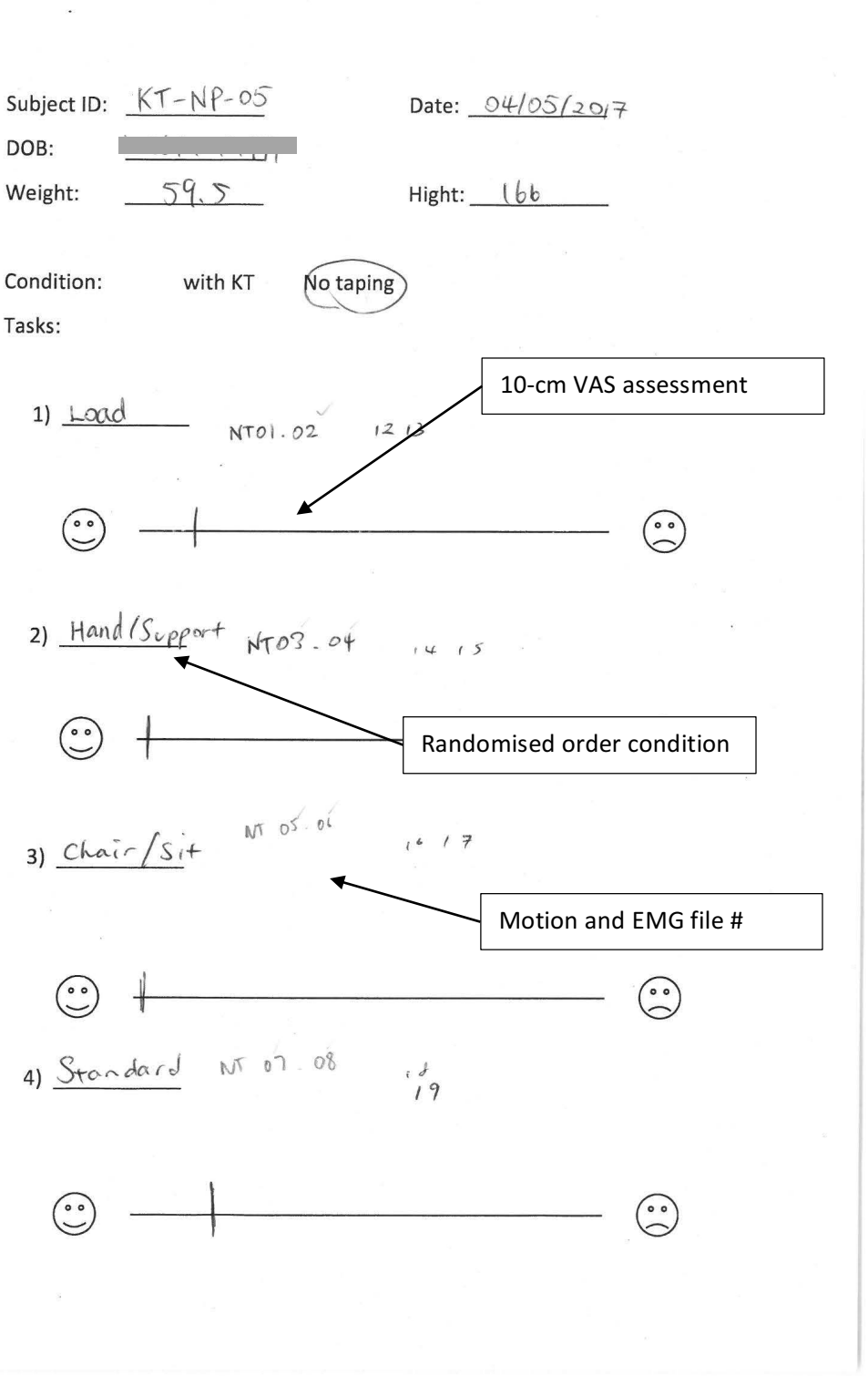
All data including the corresponding name/number data and any other personal information will be stored securely held on a separate server, which require a password, at Human Performance Lab, Queen Mary, University of London, and can be accessed by the QMUL research team involved in the investigation and analysis only.

The aim is to publish the project; however, no identifiable details will be made public.

15 Information for participants
See attachment
16 Consent
See attachment
17 Signature of applicant and authorising signatories.
 **Principal Investigator** **Other Applicant(s)** **(Head of Department)**

APPENDIX C – DATA COLLECTION SHEETS

VAS scale and data collection note



Short Form McGill Pain Questionnaire

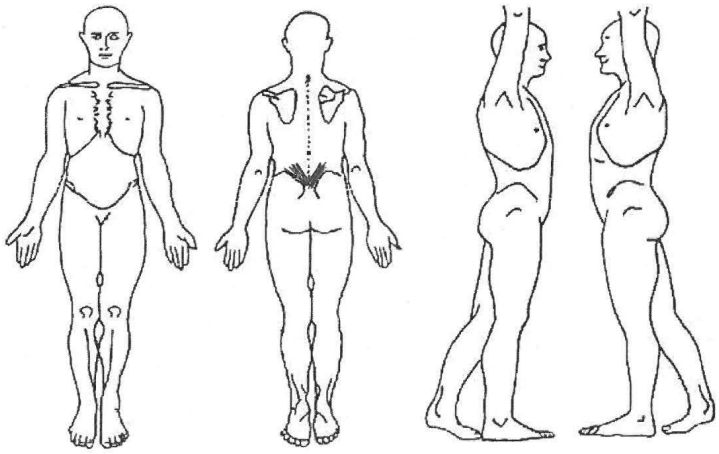
Participant Code: 05

Short Form McGill Pain Questionnaire

Check the column to indicate the level of your pain for each word, or leave blank if it does not apply to you.

	Mild	Moderate	Severe
Throbbing			
Shooting			
Stabbing			
Sharp			
Cramping			
Gnawing			
Hot-burning			
Aching		✓	
Heavy	✓		
Tender	✓		
Splitting			
Tiring - Exhausting			
Sickening			
Fearful			
Cruel-Punishing			

Indicate on the chart below where your pain or areas of pain are located



How severe is your pain?

No pain — Worst pain imaginable

Modified Marx Activity Rating Scale

Participant code: 05

Modified Marx Activity rating scale

Please indicate how often you performed each activity in your healthiest and most active state, **in the past year.**

	<1 per month	1 per month	1 per week	2-3 times per week	4 + times per week
Running: Running while playing sport or jogging			✓		
Cutting: Changing directions while running	✓				
Pivoting: Turning your body with your foot planted while playing a sport. For example: skiing, skating, kicking, throwing, hitting a ball (golf, tennis, squash) etc		✓			
Rowing	✓				
Cycling				✓	
Swimming	✓				

Adapted from : Marx, R.G, Stump, T.J, Jones, E.C, Wickiewicz, T.L., Warren, R.F. (2001)

APPENDIX D – PEER REVIEWED PUBLICATION

FASCIA SCIENCE AND CLINICAL APPLICATIONS: OBSERVATIONAL LABORATORY STUDY

Journal of Bodywork & Movement Therapies (2016) 20, 898–905

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/jbmt

FASCIA SCIENCE AND CLINICAL APPLICATIONS: OBSERVATIONAL LABORATORY STUDY

Does 'Kinesio tape' alter thoracolumbar fascia movement during lumbar flexion? An observational laboratory study

Shihfan Jack Tu, MSc [a], Roger C. Woledge, PhD [a], Dylan Morrissey, PT PhD [a,b,*]

[a] *Sport and Exercise Medicine, Queen Mary University of London, Mile End Hospital, Bancroft Road, London, E1 4DG, UK*
[b] *Physiotherapy Department, Bart's Health NHS Trust, London, UK*

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KEYWORDS
Kinesio tape;
Thoracolumbar fascia;
Ultrasound;
Range of motion

Summary *Background:* Changes in thoracolumbar fascial thickness, structure and shear strain are associated with lower back pain (LBP). Therapeutic taping techniques such as Kinesio-Taping (KT) are increasingly used to treat LBP, albeit with variable effects and unclear mechanisms. However, evidence for quantifying how treatment effects in vivo fascia properties is inadequate. We therefore aimed to explore taping mechanisms using an in vivo ultrasound measurement.
Methods: Thoracolumbar ultrasound videos of known orientations and positions were taken from 12 asymptomatic participants (8 males and 4 females, aged 22.9 ± 3.59) while performing velocity-guided lumbar flexion with and without KT applied. An automated algorithm using cross-correlation to track contiguous tissue layers across sequential frames in the sagittal plane, was developed and applied to two movements of each subject in each taping condition. Differences of inter-tissue movements and paracutaneous translation at tissue boundaries were compared.
Results: Significant reduction in the mean movement of subcutaneous tissue during lumbar flexion before and after taping was found. There was no difference in other observed tissue layers. Tissue paracutaneous translations at three boundaries were significantly reduced during lumbar flexion when KT was applied (skin-subcutaneous: 0.25 mm, $p < 0.01$; subcutaneous-perimuscular tissue: 0.5 mm, $p = 0.02$; and perimuscular-muscle: 0.46, $p = 0.05$). No overall reduction in lumbar flexion was found ($p = 0.10$).
Conclusions: KT reduced subcutaneous inter-tissue movement and paracutaneous translation in the superficial thoracolumbar fascia during lumbar flexion, and the relationship of such difference to symptomatic change merits exploration. Combining ultrasound data with muscle

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http://dx.doi.org/10.1016/j.jbmt.2016.04.007

activation information may be useful to reveal potential mechanisms of therapeutic taping in patients with LBP.

Introduction

Kinesio-Taping (KT), developed by Kase et al. in the 1970s, is a popular taping technique (Kase et al., 2003a). Despite a poor understanding of its true effect or mechanism of action, widespread use of the technique has become an interesting and relatively new modality in treating musculoskeletal conditions, including rotator cuff tendonitis (Thelen et al., 2008), shoulder impingement syndrome (Kaya et al., 2011), acute whiplash (Gonzalez-Iglesias et al., 2009), patellofemoral pain (Akbas et al., 2011), and chronic lower back pain(Castro-Sanchez et al., 2012; Paoloni et al., 2011). This popularity may be due to the structure of the tape, which can be stretched along the longitudinal axis yet allows free movement of the taped body area. Other features of KT, such as its being thin, latex free and anti-allergenic or able to feature fashionable colours and patterns, may also be a marketing strength which has augmented the propensity to use KT. A common use is in flexion related lower back pain (AlBahel et al., 2013; Paoloni et al., 2011).

Lower back pain is a common disorder with a high recurrence and lifetime prevalence (Hoy et al., 2010). The condition represents a large socioeconomic burden to the healthcare system and society more generally due to the costs of treatment and time lost from work (Manchikanti et al., 2008; Martin et al., 2008). The cause of back pain remains unclear in over 80% of cases, even though some common spinal disorders related to LBP have been defined (Videman and Battié, 2012). Although current clinical practice guidelines recommend several treatments for LBP, most randomised controlled trials have shown that these treatments provide only mild to moderate clinical improvement in LBP patients (Van Tulder et al., 2006). The same guidelines also state that no difference has been proved between the various modalities of exercise-based therapy as well as manual therapy techniques. We therefore need better treatments. KT has been evaluated as a possible adjunct treatment. By adjunct, we mean a facilitator of treatments with longer term effect.

A particular problem in understanding the role of KT in lower back pain treatment is that there are many ways of applying KT, with different suggested underlying *mechanisms* yet the literature has focussed on *effects* possibly to the detriment of our understanding and application. Five systematic reviews (Kalron and Bar-Sela, 2013; Morris et al., 2013; Mostafavifar et al., 2012; Parreira et al., 2014a; Williams et al., 2012) examining the clinical effects of KT application in musculoskeletal and sports related injuries concluded that KT may only have a small beneficial effect. However, the reports are somewhat confused by the diversity of taping approaches combined in evidence synthesis. All reviews are discussing similar materials that include some low quality trials or small sample sizes. The most recent review (Parreira et al., 2014a) even directly concluded that current evidence does not support the clinical importance of KT, because the benefit effect founded it the current studies were either too small to be clinically worthwhile or not significant. To summarise, current evidence may not be enough to support the efficacy of KT application. However, judging effects without clarity about the underlying mechanism of KT may confound clinical studies. A few of these have evaluated this therapeutic tool and were either looking at different conditions or investigating with a diversity of approaches. To date, there is no robust evidence to link pathophysiological effects and actual body reactions triggered by KT, thus no clear direction has emerged to suggest these considerations translate into clinical practice.

Due to a poor understanding of the mechanism of chronic non-specific lower back pain, treatment techniques applied to this condition tend to have an unconfirmed mechanism of action. A hypothesized pathophysiology of lower back pain indicated to the thoracolumbar fascia, although this currently remains unclear (Langevin and Sherman, 2007; Malanga and Colon, 2010). In a similar fashion, patients with chronic lower back pain for longer than 12 months have been found to increase the thickness of their thoracolumbar fascia (Langevin et al., 2009); and the fascia shear strain has been reduced when compared with those without LBP (Langevin et al., 2011). However, neither the causative mechanisms underlying these changes nor the relationship to the symptoms are clear. This pathophysiological difference could therefore potentially suggest a reason for further investigation on the mechanism of action when KT is applied.

The aim of the present study was therefore to explore the effect of KT application on the thoracolumbar fascia using a newly developed ultrasound tool. This exploration could provide a better understanding on how the thoracolumbar soft tissue responds to therapeutic taping, which could become a useful guideline for treatment selection. The objectives were to measure soft tissue movement in the thoracolumbar area; and lumbar range of motion when performing the lumbar flexion task with and without KT.

Methods

Study design

A snap shot observational study was carried out to develop the methodology and to explore potential taping mechanisms. Asymptomatic participants were recruited to develop empirical and analytical methodology, and the

preliminary results were analysed to ensure the method could be applied to symptomatic cohort.

Twelve subjects (8 males; Age 22.9 ± 3.59; BMI 21.22 ± 2.65), who had no history of lower back pain or any other chronic pain that had limited their work or daily activities, were invited to participate in the study.

General procedure

Subjects were asked to perform speed-guided lumbar flexion-extension tasks in two states (without taping and with KT) in the data collection session; the collection procedure is shown in Fig. 1. A metronome set at 90 beats per minute was used to provide a time guide. Subjects were advised to finish their forward bending in a period of four beats and return to a natural position at the same speed. Subjects were allowed to have several practice runs to get familiar with this experimental movement in order to perform the action smoothly and avoid unnatural action or pauses while the exercise was taking place. The same procedure was done twice on initial subjects on different days to test its reliability. The speed and range of motion (ROM) might be slightly different between subjects, however kinematic data were recorded using a motion capture system for later normalisation. Relative movement and trunk angle registration were used in data analysis.

Taping procedure

Several application techniques are currently used in treating patients with LBP. To minimise the effect of individual therapists, in this study taping was applied using I-shape strips taped over one erector spinae muscle, parallel to the spinous process of the lumbar vertebrae (Fig. 2). Before taping, subjects' skin was checked to make sure that there was no pre-existing skin lesion over the taping area. A small piece of KT was then applied to the arm for 20 min before the trial to ensure the subject was not allergic to the tape. KT was applied to a single side of the muscle, a computerised random number being used to decide which side to tape. Tapes were applied with 10% of tension (paper-off tension) from the top of the first sacrum up to the bottom edge of the T12 vertebrae (treatment area). Two anchors with 0% tension were then applied above and below the treatment area. To control taping tension, the length of the taping area was measured before taping, and the tape was cut accordingly. As recommended by the KT application guidelines (Kase et al., 2003b), while applying taping the patients were asked to flex their lumbar spine to their natural end (they were asked to touch the toes) to stretch the erector spinae muscle. Consequently, the tape created convolutions when the subject stood in neutral. In order to perform ultrasound scanning, a 5 × 1 cm window beside the L2 and L3 vertebrae was cut on the tape strip (Fig. 2).

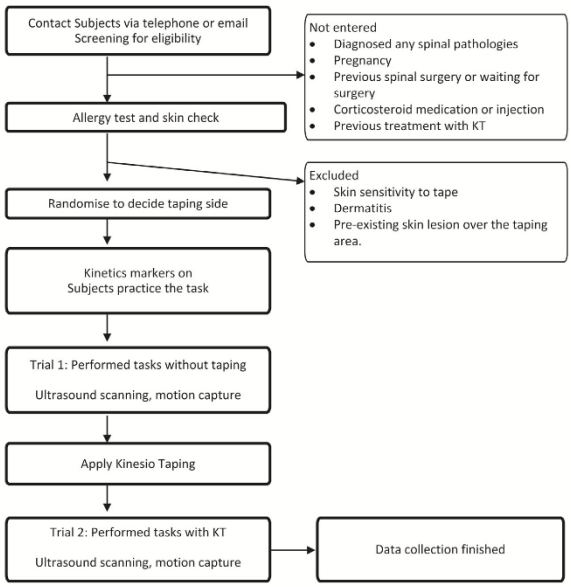

Figure 1 Flowchart of data collection procedure.

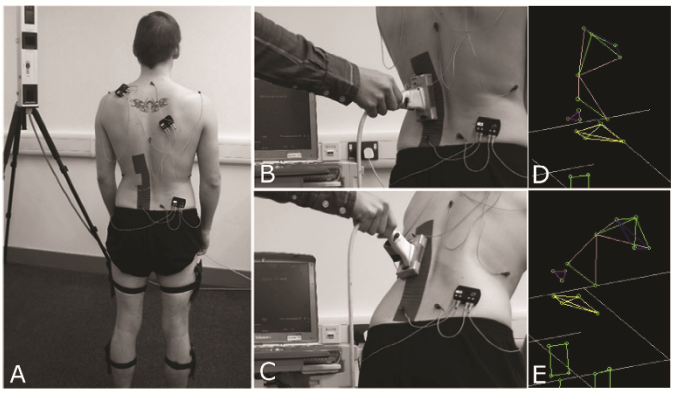

Figure 2 Demonstration of KT application and data collection. A: KT application with cut-out, and motion capture marker positions. B&C: ultrasound scanning during movement; the probe head was attached with a frame and 3 motion markers. D&E: examples of stick figures in the motion capture system.

Ultrasound collection

An ultrasound machine (Voluson i, GE Healthcare; WI, USA) with a frequency 4–12 MHz linear probe (GE 12L – RS, GE Healthcare; WI, USA) was used to collect data in the present study. Parasagittal b-mode cine ultrasound images of the lumbar tissue movements were collected synchronously with body kinematic data. Although the taping effect may appear in all areas where KT was applied, we have to choose a small window to observe due to the probe size. The transducer was placed at a point 3 cm lateral to the middle of the L2 and L3 spinous processes (Fig. 2), because the fascia planes are the most parallel to the skin in the higher level of the lumbar area (Langevin et al., 2009) which provided better accuracy of image processing. When performing trunk flexion, the caudal end of the transducer was stabilised on the subject's skin, and the skin was allowed to slide at the rostral end. The overall lateral and rostral translation of the ultrasound transducer was prevented during flexion movement. To ensure image quality, an ultrasound probe holder was made to avoid lateral translation and swing (Fig. 2).

Motion capture

Active light emitting diodes (LEDs) were attached to the following body landmarks: acromion, spinal process of 7th cervical and 7th thoracic vertebrae, 10th rib angles, sternal angle, anterior superior iliac spine, posterior superior iliac spine. LED clusters were attached to thighs and shanks (Fig. 2). Three extra LEDs were used to monitor the motion of the ultrasound probe and record its orientation (Fig. 2). The three dimensional position of these LEDs was determined with an accuracy of ±1 mm by using a CODA motion analysis system (v 6.79. Charnwood Dynamics; Leicester, UK) at a sampling rate of 200 Hz. The range of motion was calculated by processing the marker position retrieved from segment orientations (sum of trunk and pelvis orientation).

Ultrasound tracking algorithm

A customised MATLAB (R2015a, Mathwork; MA, USA) based algorithm was used in the present study. The programme is designed to track fascia movements in 3D ultrasound images using a cross-correlation feature tracking method which is common in tendon research (Chernak and Thelen, 2012).

B-mode ultrasound videos were converted into an echogenicity matrix frame-by-frame. An investigator identified boundaries between skin, fascia and muscles according to echogenicity; the intra-investigator reliability of boundary identification was high (ICC = 0.98). The movements of tissue were then tracked by the programme. The centre area of each layer was defined as an area of interest. The programme automatically searched the contiguous area, and detected the movements within every layer. The positions were recorded and the routes of tissue movement were mapped (Fig. 3). Further movement calculations, including moving distance and boundary gliding, were carried out according to the map.

paracutaneous tissue translation

This term was used to describe one of the main outcome measures which is the relative movements of two layers on either side of a tissue boundary, approximately parallel to the skin surface. Several terms were considered by the author before submitting. 'Shear strain', the ratio of deformation to original dimensions, was used in previous studies, because shape changes of the thoracolumbar fascial images were analysed and discussed (Langevin et al., 2011). However, the thoracolumbar tissue movements were monitored and the difference on the either

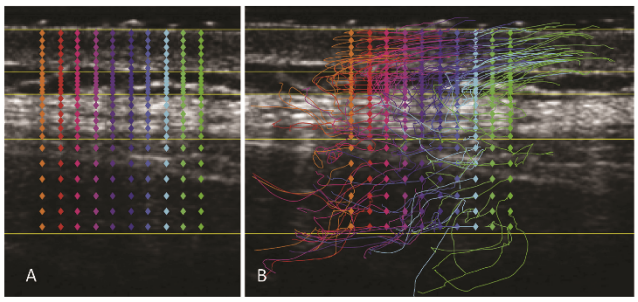

Figure 3 Demonstration of ultrasound tracking algorithm. A: an example of layer recognition with 60 points of interest. B: an example of results of 60 tissue movement routes during the lumbar flexion task.

side of tissue boundaries were computed in the present study and do not accurately fit the definition of shear strain. 'Gliding', which is a common term to describe movement at joint surfaces, was also considered. Although boundaries on the sub-cutaneous lumbar tissue can be seen, they are not clear interface unlike joint surfaces. Connective tissues are connecting one layer to another and there are movement translations through layers. Therefore, we decided to use 'paracutaneous tissue translation' to describe the observed phenomenon.

Statistics

Statistical analysis was performed using MATLAB Statistical toolbox (R2015a, Mathwork; MA, USA). Descriptive statistics were used to characterize the study sample. The paired t-test was used to test differences of tissue movements and paracutaneous translation at boundaries between conditions of no KT application and with KT. Statistical analyses were conducted at a 95% confidence level. P value < 0.05 was considered significant.

Results

Movements of the subcutaneous zone (which contains fat and superficial fascia) were significantly reduced during the lumbar flexion (forward bending) task when KT was applied (Fig. 4A), though no difference was found in skin and muscle movements. Fig. 4B reveals the tissue movements when subjects were performing the lumbar extension (return to initial posture) task. There were no differences before and after KT was applied.

The inter-tissue paracutaneous translation in skin-subcutaneous and subcutaneous-perimuscular boundaries was significantly reduced during the lumbar flexion task when KT was applied (Table 1). Similarly, paracutaneous translation was also moderated in the fascia-muscle boundary; however, the difference was not statistically significant ($p = 0.05$). No difference of paracutaneous inter-tissue translation was found when the subjects performed the return-to-stand task.

No significant differences in ROM was found after KT was applied. The mean lumbar flexion range was $91.19 \perp 3.33^{\circ}$ before taping, and was $92.47 \perp 1.80^{\circ}$ after ($p = 0.10$, $df = 11$).

Discussion

The aim of the present study was to assess the impact of KT on the movements of the thoracolumbar tissue. Most studies concentrate on KT's effect on pain and symptoms (Williams et al., 2012), however, the evidence exploring its actual mechanisms is inadequate. It was therefore likely beneficial to understand the effect of KT on the skin and sub-cutaneous tissues in asymptomatic subjects during whole-body movements, in order to understand mechanisms and perhaps what kind of patients are most likely to benefit, myofascial related LBP for example. By understanding the KT mechanisms in those without pain, we will be able to compare any tissue movement observed in people with pain. Furthermore, comparison of symptomatic responders and non-responders may help us to understand pain mechanisms and response characteristics, therefore targeting treatment better.

The result of the present study shows that KT limited tissue movements in the subcutaneous zone, which is the area that contains fat tissue and superficial fascia, when the subjects were performing lumbar flexion tasks. However, KT did not repeat the alterations when the subjects were performing return-to-stand tasks. Interestingly, even though the tissue movements were moderated by KT, the mean angle of lumbar flexions was slightly increased after taping. The result of ROM change was not statistically significant ($p > 0.05$), however. These results suggest that KT is likely to change actions of the subcutaneous tissue.

The ROM results of the present study do not corroborate the results of the study of Yoshida et al. Yoshida and Kahanov (2007), which reported a significant increase in the ROM upon application of KT, instead they support the findings of another KT study (Lemos et al., 2014) which reported no significant immediate improvement of ROM after applying KT. However, evidence on ROM improvement is currently conflicting. This may be due to two reasons:

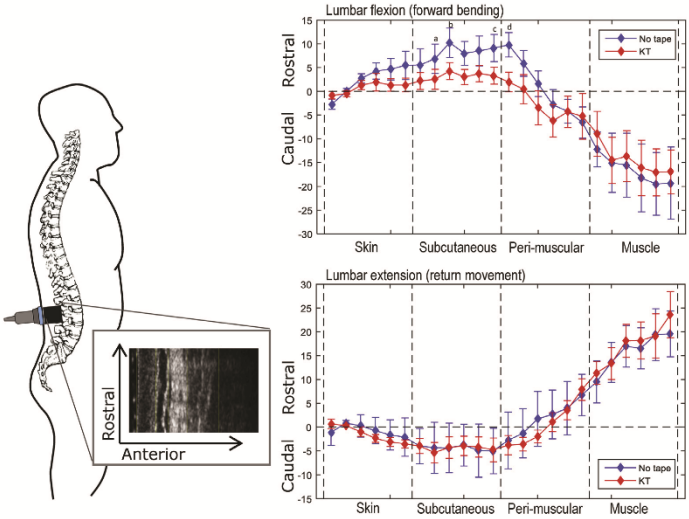

Figure 4 Comparison of tissue movements before and after KT applied. Red lines represent mean movements when KT was applied, while blue represents data without KT application. Error bars are standard error across 12 subjects. Scale unit: pixels (1 pixel = 0.12 mm). Statistics: a. $p < 0.05$, $T = 1.83$, $df = 11$; b. $p < 0.05$, $T = 1.82$, $df = 11$; c. $p = 0.03$ $T = 0.63$, $df = 11$; d. $p = 0.03$, $T = 1.01$, $df = 11$.

Table 1 paracutaneous tissue translation comparisons (t-test; unit: pixels).

	Interface	NT		KT		p-value
		Mean	Std.	Mean	Std.	
Lumbar Flexion	Skin/Sub	0.52	0.34	0.27	0.27	<0.01*
	Sub/Fascia	0.88	0.74	0.38	0.29	0.02*
	Fascia/Muscle	0.94	0.60	0.48	0.42	0.05
Return	Skin/Sub	0.35	0.38	0.33	0.49	0.43
	Sub/Fascia	0.52	0.72	0.31	0.20	0.20
	Fascia/Muscle	0.49	0.35	0.60	0.33	0.19

firstly, results were produced by different assessment methods; for example, Yoshida measured the distance between the finger and the toes and Lemos measured distance changes on lower back skin markers (Schober's test), although they both asked subjects bend to touch their toes. While in the present study, ROM were calculated by kinematic data (trunk and pelvis orientation). Second, the taping techniques were slightly different in each study. It is therefore difficult to compare results from the different studies.

Apart from ROM, the study's result provides unexpected findings that the method of KT used reduces overall movements and tissue paracutaneous translation between tissue layers. This may conflict with the findings published by Langevin et al. Langevin et al., (2011). which suggested a 20% decrease in shear strain in the thoracolumbar fascia was predominant in chronic lower back pain patients, therefore challenging the theory that decreased shear predisposes individuals to developing chronic lower back pain, and that KT could be used to treat this. However, the findings from this previous paper don't imply causality, due to a lack of established causal relationships between LBP and altered fascia characteristics. It could be that the reduction of shear strain is an adaptive change to reduce LBP during movement. Further research to help identify these factors is needed.

There were a few limitations in the present study. Firstly, we did not compare the effect with a sham taping or different application methods - for example using different direction of tape tension, however, keeping the study procedure as simple as the standard taping method, which was introduced in KT books and prior studies (Added et al., 2013; Kase et al., 2003b; Parreira et al., 2014b), provides a clearer and focused view in research findings. Apart from KT, there are also other types of tapes are currently used in the clinical practice, McConnell tape and dynamic tape, for example. Only one particular methods of KT was applied in the present study, therefore it is uncertain if similar effect can be delivered using different tape or methods. More studies is required to answer this as no studies were looking at taping effect on tissue movement has been published.

Second, in order to capture the ultrasound videos of the taped area, a rectangular portion of the tape was removed to allow placement of the probe. This may have affected

the taping effect to the area from which results were retrieved and therefore may have had an impact upon overall movement and paracutaneous translation between layers. Unfortunately there was no obvious method that could be applied to avoid cutting a window in the tape, owing to the current limitation of ultrasonography techniques – ultrasonic waves do not penetrate KT. Another potential limitation was that the assessment could only be performed at the level of second and third lumbar spine due to the size of the ultrasound probe view. KT may affect movements of the whole thoracolumbar facia. Nonetheless, the scanning position was chosen because of the flat surface in this level making the assessment and retrieval of higher quality images easier (Langevin et al., 2009). This may warrant further research in areas where mobility is more restricted. This would also offer a greater idea of the effects of KT on connective tissue and pathogenesis for lower back pain (Langevin and Sherman, 2007).

The present study did not monitor muscle activity during the tasks. Information about muscle activity should be considered for future research due to findings in other studies which note an altered muscle activity when KT was applied to other portions of the body (Gomez-Soriano et al., 2014; Martinez-Gramage et al., 2016). It has also been suggested that the reduction of paracutaneous boundary translation may be the result of impaired neuromuscular control and recruitment patterns of muscles during trunk movements. This has been shown to be associated with chronic lower back pain (Jacobs et al., 2009; MacDonald et al., 2009), and therefore analysis of this electromyography data could possibly reveal the neuromuscular mechanism of KT. There has been some previous research into the effect of KT on anticipatory control of the trunk, however evidence is currently conflicting (Bae et al., 2013; Voglar and Sarabon, 2014).

Irrespective of these limitations, there is a clear effect of KT on tissue movement. Further observational studies, particularly case series work, are then required in this study area. The key future experiment is repetition of these measures in patients with LBP. What we would like to observe is what happens to the tissues when some patients benefit or don't benefit from KT based on clinical responses, for example, subjective pain scale assessments, total ROM assessments.

Conclusion

In summary, thoracolumbar tissue dynamics were altered in subjects without LBP after receiving KT application. Results suggest that KT may reduce sub-cutaneous connective tissue movements and inter-tissue translation at boundaries during lumbar flexion movement, however whether the degree or direction of change in tissue movement may represent a beneficial result after the application of KT remains uncertain.

Conflicts of interest

Dr Morrissey is part-funded by the NIHR/HEE Senior Clinical Lecturer scheme (CAT SCL-2013-04-003). This report presents independent research part-funded by the National Institute for Health Research (NIHR). The views expressed are those of the authors and not necessarily those of the NHS, the NIHR or the Department of Health.

References

Added, M.A., Costa, L.O., Fukuda, T.Y., de Freitas, D.G., Salomao, E.C., Monteiro, R.L., Costa, L.D.A., 2013. Efficacy of adding the Kinesio taping method to guideline-endorsed conventional physiotherapy in patients with chronic nonspecific low back pain: a randomised controlled trial. BMC Musculoskelet. Disord. 14, 301.

Akbas, E., Atay, A.O., Yuksel, I., 2011. The effects of additional Kinesio taping over exercise in the treatment of patellofemoral pain syndrome. Acta Orthop. traumatologica turcica 45, 335–341.

AlBahel, F., Hafez, A.R., Zakaria, A.R., Al-Ahaideb, A., Buragadda, S., Melam, G.R., 2013. Kinesio taping for the treatment of mechanical low back pain. World Appl. Sci. J. 22, 78–84.

Bae, S.H., Lee, J.H., Oh, K.A., Kim, K.Y., 2013. The effects of Kinesio taping on potential in chronic low back pain patients anticipatory postural control and cerebral cortex. J. Phys. Ther. Sci. Jpn. 1367–1371.

Castro-Sanchez, A.M., Lara-Palomo, I.C., Mataran-Penarrocha, G.A., Fernandez-Sanchez, M., Sanchez-Labraca, N., Arroyo-Morales, M., 2012. Kinesio Taping reduces disability and pain slightly in chronic non-specific low back pain: a randomised trial. J. Physiother. 58, 89–95.

Chernak, L.A., Thelen, D.G., 2012. Tendon motion and strain patterns evaluated with two-dimensional ultrasound elastography. J. biomechanics 45, 2618–2623.

Gomez-Soriano, J., Abian-Vicen, J., Aparicio-Garcia, C., Ruiz-Lazaro, P., Simon-Martinez, C., Bravo-Esteban, E., Fernandez-Rodriguez, J.M., 2014. The effects of Kinesio taping on muscle tone in healthy subjects: a double-blind, placebo-controlled crossover trial. Man. Ther. 19, 131–136.

Gonzalez-Iglesias, J., Fernandez-De-Las-Penas, C., Cleland, J., Huijbregts, P., Del Rosario, G.V.M., 2009. Short-term effects of cervical Kinesio taping on pain and cervical range of motion in patients with acute whiplash injury: a randomized clinical trial. J. Orthop. sports Phys. Ther. 39, 515.

Hoy, D., Brooks, P., Blyth, F., Buchbinder, R., 2010. The epidemiology of low back pain. Best Pract. Res. Clin. rheumatology 24, 769–781.

Jacobs, J.V., Henry, S.M., Nagle, K.J., 2009. People with chronic low back pain exhibit decreased variability in the timing of their anticipatory postural adjustments. Behav. Neurosci. 455–458, 2009 APA, all rights reserved., United States.

Kalron, A., Bar-Sela, S., 2013. A systematic review, of the effectiveness of Kinesio Taping (R) – fact or fashion? Eur. J. Phys. Rehabilitation Med. 49, 699–709.

Kase, K., Wallis, J., Kase, T., 2003a. Clinical Therapeutic Applications of the Kinesio Taping Method, second ed. Kinesio Taping Association.

Kase, K., Wallis, J., Kase, T., Association, K.T., 2003b. Clinical Therapeutic Applications of the Kinesio Taping Methods. Kinesio Taping Assoc.

Kaya, E., Zinnuroglu, M., Tugcu, I., 2011. Kinesio taping compared to physical therapy modalities for the treatment of shoulder impingement syndrome. Clin. Rheumatol. 30, 201–207.

Langevin, H.M., Fox, J.R., Koptiuch, C., Badger, G.J., Greenan-Naumann, A.C., Bouffard, N.A., Konofagou, E.E., Lee, W.-N., Triano, J.J., Henry, S.M., 2011. Reduced thoracolumbar fascia shear strain in human chronic low back pain. BMC Musculoskelet. Disord. 12, 203.

Langevin, H.M., Sherman, K.J., 2007. Pathophysiological model for chronic low back pain integrating connective tissue and nervous system mechanisms. Med. hypotheses 68, 74–80.

Langevin, H.M., Stevens-Tuttle, D., Fox, J.R., Badger, G.J., Bouffard, N.A., Krag, M.H., Wu, J., Henry, S.M., 2009. Ultrasound evidence of altered lumbar connective tissue structure in human subjects with chronic low back pain. BMC Musculoskelet. Disord. 10.

Lemos, T.V., Albino, A.C.G., Matheus, J.P.C., Barbosa, AdM., 2014. The effect of Kinesio taping in forward bending of the lumbar spine. J. Phys. Ther. Sci. 26, 1371–1375.

MacDonald, D., Moseley, G.L., Hodges, P.W., 2009. Why Do Some Patients Keep Hurting Their Back? Evidence of Ongoing Back Muscle Dysfunction during Remission from Recurrent Back Pain. Pain, Netherlands, pp. 183–188.

Malanga, G.A., Colon, E.J.C., 2010. Myofascial low back pain: a review. Phys. Med. rehabilitation Clin. N. Am. 21, 711–724.

Manchikanti, L., Singh, V., Datta, S., Cohen, S.P., Hirsch, J.A., 2008. Comprehensive review of epidemiology, scope, and impact of spinal pain. Pain physician 12, E35–E70.

Martin, B.I., Deyo, R.A., Mirza, S.K., Turner, J.A., Comstock, B.A., Hollingworth, W., Sullivan, S.D., 2008. Expenditures and health status among adults with back and neck problems. Jama 299, 656–664.

Martinez-Gramage, J., Merino-Ramirez, M.A., Amer-Cuenca, J.J., Lison, J.F., 2016. Effect of Kinesio Taping on gastrocnemius activity and ankle range of movement during gait in healthy adults: a randomized controlled trial. Phys. Ther. Sport 18, 56–61.

Morris, D., Jones, D., Ryan, H., Ryan, C., 2013. The clinical effects of Kinesio® Tex taping: a systematic review. Physiother. theory Pract. 29, 259–270.

Mostafavifar, M., Wertz, J., Borchers, J., 2012. A systematic review of the effectiveness of kinesio taping for musculoskeletal injury. Phys. Sportsmed. 40, 33–40.

Paoloni, M., Bernetti, A., Fratocchi, G., Mangone, M., Parrinello, L., Cooper, M.D., Sesto, L., Di Sante, L., Santilli, V., 2011. Kinesio Taping applied to lumbar muscles influences clinical and electromyographic characteristics in chronic low back pain patients. Eur. J. Phys. Rehabilitation Med. 47, 237–244.

Parreira, PdCS., Costa, LdCM., Hespanhol Junior, L.C., Lopes, A.D., Costa, L.O.P., 2014a. Current evidence does not support the use of Kinesio Taping in clinical practice: a systematic review. J. Physiother. 60, 31–39.

Parreira, PdCS., Costa, LdCM., Takahashi, R., Junior, L.C.H., da Luz Junior, M.A., da Silva, T.M., Costa, L.O.P., 2014b. Kinesio Taping to generate skin convolutions is not better than sham taping for people with chronic non-specific low back pain: a randomised trial. J. Physiother. 60, 90–96.

Thelen, M.D., Dauber, J.A., Stoneman, P.D., 2008. The clinical efficacy of Kinesio tape for shoulder pain: a randomized, double-blinded, clinical trial. J. Orthop. Sports Phys. Ther. 38, 389.

Van Tulder, M., Becker, A., Bekkering, T., Breen, A., Gil del Real, M.T., Hutchinson, A., Koes, B., Laerum, E., Malmivaara, A., 2006. Chapter 3 European guidelines for the management of acute nonspecific low back pain in primary care. Eur. Spine J. 15, s169–s191.

Videman, T., Battié, M.C., 2012. Commentary: back pain epidemiology—the challenge of case definition and developing new ideas. Spine J. 12, 71–72.

Voglar, M., Sarabon, N., 2014. Kinesio taping in young healthy subjects does not affect postural reflex reactions and anticipatory postural adjustments of the trunk: a pilot study. J. Sports Sci. Med. 13, 673–679.

Williams, S., Whatman, C., Hume, P.A., Sheerin, K., 2012. Kinesio taping in treatment and prevention of sports injuries a meta-analysis of the evidence for its effectiveness. Sports Med. 42, 153–164.

Yoshida, A., Kahanov, L., 2007. The effect of winesio taping on lower trunk range of motions. Res. sports Med. 15, 103–112.

APPENDIX E – CONFERENCE PAPERS

Tu SJ, Woledge R, Morrissey D (2015). *Measurement of the effects of 'Kinesio-taping' on in vivo thoracolumbar fascia movement using 3d ultrasound: methodological development and reliability.* XXV Congress of the International Society of Biomechanics, Glasgow, UK.

Connective Tissue

AS-0398

MEASUREMENT OF THE EFFECTS OF 'KINESIO-TAPING' ON IN VIVO THORACOLUMBAR FASCIA MOVEMENT USING 3D ULTRASOUND: METHODOLOGICAL DEVELOPMENT AND RELIABILITY

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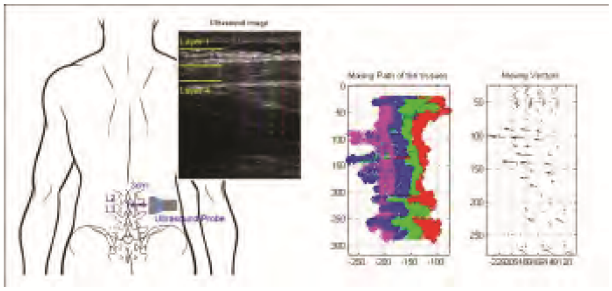
Introduction and Objectives: Therapeutic taping techniques are increasingly used to treat low back pain (LBP) [1, 2, 3], albeit with variable effects and unclear mechanisms. Changes in thoracolumbar fascial thickness, structure and shear strain are associated with LBP [4, 5], however methods for quantifying in vivo fascia properties are inadequate. We therefore aimed to develop a reliable in vivo measurement technique to enable exploration of taping mechanisms.

Methods: Ultrasound videos of known orientation and position were taken of 9 normal participants (male and female, aged 27.3 ± 2.04, BMI 22.98 ± 3.10) while performing velocity-guided lumbar flexion with and without taping. An automated algorithm using cross-correlation to track contiguous tissue layers across sequential frames, in two planes, was developed and applied to two movements of each subject in each taping condition. Reliability was assessed using the intra-class correlation coefficient (ICC 2, 1), limits of agreement (LOAs) were calculated for each assessment and systematic differences tested with a Student's t-test.

Results: The mean movements of thoracolumbar tissue during lumbar flexion before and after taping (figure 1) showed strong reliability within subjects ICC both when subjects were moving without tape applied (ICC = 0.82) and with Kinesio-taping applied (ICC = 0.82). No significant differences was found (No tape, p = 0.32, t = 1.00; tape, p = 0.90, t = -0.13). Intra-observer analysis revealed acceptable LOAs for both measurements when subjects were taped and not taped. The study was not powered to reveal differences between taping conditions, and none was revealed, however a sample size calculation suggested that 80 subjects would be required at 80% power and 5% significance levels. It must be noted these were normal subjects rather than those with pain.

Figure:



Caption: Ultrasonography tracking analysis. (A) The Ultrasound probe was placed 3 cm lateral to the midpoint of a line joining L2 and L3 spinous processes. In the tracking programme, multiple tracking targets (middle area between 4 red

dots) were drawn. (B) Movements in each position were tracked and recorded as a route map. (C) A vector field plot based on the route map was calculated to quantify tissue movements in each plane. Blue vectors indicate in-image movement direction and amount. (Plot unit = pixels)

Conclusion: Movement of relative thoracolumbar fascia, muscle and fatty tissue and underlying tissues could be reliably quantified during lumbar flexion in vivo using real-time ultrasound. The reliability was similar for both taped and untaped conditions. Next steps include validity analysis and testing in subjects with low back pain to investigate possible mechanisms of taping therapies.

Table: Table: Intra-class correlation coefficient and limits of agreement

	Analysis 1	Analysis 2	P value	ICC	$MEAN_{diff}$	SD_{diff}	Lower LOA	Upper LOA
without taping	2.15 ± 2.76	1.91 ± 2.3	0.32	0.82	0.23	1.97	-3.63	4.09
with taping	1.76 ± 1.78	1.78 ± 2.53	0.90	0.82	-0.02	1.69	-3.33	3.29

Caption: MEAN diff, mean difference between measurememts; ICC, intraclass correlation coefficient; LOA, limits of agreement; SD diff, SD of difference between measurements. (Figure unit = pixels, 1 pixels = 0.12 mm)

References: [1] Yoshida et al., Res Sports Med, 15: 103-112, 2007.

[2] Castro-Sánchez et al., J Physiother 58: 89-95, 2012.

[3] Chen et al., Clin Rehabil, 26: 924-933, 2012.

[4] Langevin et al., BMC Musculoskelet Disord, 10:151, 2009.

[5] Langevin et al., BMC Musculoskelet Disord, 12:203, 2011.

[6] Martin Bland et al. The lancet 327: 307, 1986.

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Tu SJ, Woledge R, Morrissey D (2015). *Measurement of the Effects of 'Kinesio-Taping' in Vivo Thoracolumbar Fascia Movement Using Ultrasound: Method Development and Observational Study.* Fourth International Fascia Research Congress, Washington DC, USA. (Winner of JBMT Abstract Award)

References:

[1] Ou Z, Li S, Li Q, Chen X, Liu W, Sun X. Duchenne muscular dystrophy in a female patient with a karyotype of 46,X,i(X)(q10). Tohoku J Exp Med. 2010 Oct;222(2):149-53.

[2] DUARTE M. Análise estabilográfica da postura ereta humana quase-estática. Tese de Livre docência, USP, 2000 http://www.teses.usp.br/teses/disponiveis/livredocencia/39/tde-07022007-070941/pt-br.php (accessed 11.03.15.).

http://dx.doi.org/10.1016/j.jbmt.2015.07.002

Measurement of the effects of 'Kinesio-Taping' in vivo thoracolumbar fascia movement using ultrasound: Method development and observational study

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Background: Changes in thoracolumbar fascial thickness, structure and shear strain are associated with low back pain (LBP) [1, 2], and therapeutic taping such as Kinesio-Taping (KT) techniques are increasingly used to treat LBP [3, 4], albeit with variable effects and unclear mechanisms. However, evidences for quantifying the treatment effects in vivo fascia properties are inadequate. We therefore aimed to develop a reliable in vivo measurement technique to enable exploration of taping mechanisms.

Methods: Thoracolumbar ultrasound videos of known orientation and position were taken from 12 normal participants (male and female, aged 22.9 ± 3.59) while performing velocity-guided lumbar flexion with and without taping. An automated algorithm using cross-correlation to track contiguous tissue layers across sequential frames, in two planes, was developed and applied to two movements of each subject in each taping condition. Differences of tissue movements and shear movements in tissue boundaries were tested with paired t-test.

Results: Significant differences in mean movements of subcutaneous tissue during lumbar flexion before and after taping were found (figure A). No difference in other observed tissue layers. Shear movements in three boundaries (skin-subcutaneous tissue, subcutaneous-perimuscular tissue, and perimuscular-muscle) were significant reduced during lumbar flexion when KT was applied.

Conclusions: Preliminary results suggest that KT may reduce tissue movements and shear during lumbar flexion, however what direction of change in tissue movement may represents a beneficial result after applied KT is uncertain. Combine these results with kinematics and muscle activation data may be useful to fully discover the effects mechanisms of therapeutic taping in patient with LBP.

http://dx.doi.org/10.1016/j.jbmt.2015.07.003

Caption: Comparison of tissue movements and tissue boundary shear before and after KT applied. Red lines and bars represent data when KT was applied, while blue represents data without tape application. Error bars are standard error across 12 subjects. Scale unit: pixels. *Significant difference ($p < .05$).

References:

[1] LANGEVIN, H. M., STEVENS-TUTTLE, D., FOX, J. R., BADGER, G. J., BOUFFARD, N. A., KRAG, M. H., WU, J. & HENRY, S. M. 2009. Ultrasound evidence of altered lumbar connective tissue structure in human subjects with chronic low back pain. *Bmc Musculoskeletal Disorders,* 10.

[2] LANGEVIN, H. M., FOX, J. R., KOPTIUCH, C., BADGER, G. J., GREENAN-NAUMANN, A. C., BOUFFARD, N. A., KONOFAGOU, E. E., LEE, W.-N., TRIANO, J. J. & HENRY, S. M. 2011. Reduced thoracolumbar fascia shear strain in human chronic low back pain. *BMC musculoskeletal disorders,* 12, 203.

[3] YOSHIDA, A. & KAHANOV, L. 2007. The effect of kinesio taping on lower trunk range of motions. *Research in sports medicine,* 15, 103-112.

[4] CASTRO-SANCHEZ, A. M., LARA-PALOMO, I. C., MATARAN-PENARROCHA, G. A., FERNANDEZ-SANCHEZ, M., SANCHEZ-LABRACA, N. & ARROYO-MORALES, M. 2012. Kinesio Taping reduces disability and pain slightly in chronic non-specific low back pain: a randomised trial. *Journal of Physiotherapy,* 58, 89-95.

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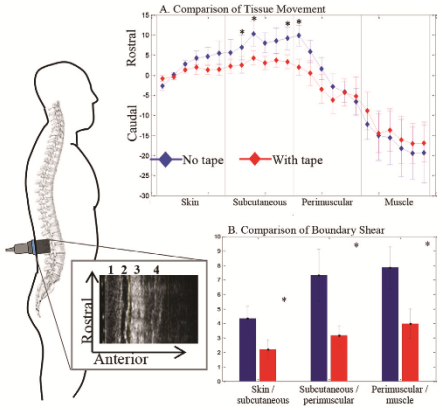

Tu SJ, Khakwani A, Morrissey D (2016). *Does tension of Kinesio-Taping produce effects in the underlying soft tissues of the thoracolumbar area? A cross-sectional observational study using ultrasound.* International Federation of Orthopaedic Manipulative Physical Therapists Scientific Conference, Glasgow, UK

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PO1-SP-068

DOES TENSION OF KINESIO-TAPING PRODUCE EFFECTS IN THE UNDERLYING SOFT-TISSUES OF THE THORACOLUMBAR AREA?

A CROSS-SECTIONAL STUDY USING ULTRASOUND

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* d.morrissey@qmul.ac.uk Dr Morrissey is part funded by the NIHR/HEE Senior Clinical Lecturer scheme. This abstract presents independent research part-funded by the National Institute for Health Research (NIHR). The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

Background

Lower back pain (LBP) is a common disorder with high recurrence and lifetime prevalence rates. Kinesio-Taping (KT), is an increasingly popular therapeutic taping technique, used to treat LBP. Previous work indicated that applying different tensions of Kinesio tapes did not affect clinical outcomes; therefore challenging the proposed mechanism of action. However, judging effects without clarity about the underlying mechanism of KT may confound clinical studies.

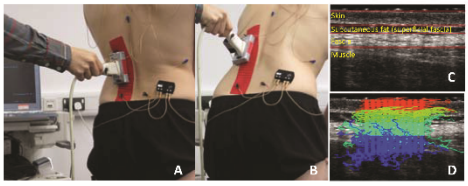

Figure1. A&B: Ultrasound scanning during movement with standard lower back Kinesio-taping. The ultrasound probe head was attached with a frame and 3 motion markers to reduce swinging artefact. **C&D:** Demonstration of ultrasound tracking algorithm. Bottom subfigure shows an example of results of 60 tissue movement routes during the lumbar flexion task.

Purpose

This study aims to (i) explore the mechanisms by which differing KT tension may act on thoracolumbar tissues; and (ii) inform LBP treatment.

Methods

Male and female asymptomatic subjects were recruited, aged 18-60. Thoracolumbar ultrasound videos of known orientation and position were taken from participants while performing velocity-guided lumbar flexion without taping and with two different tensions of KT. An automated algorithm using cross-correlation to track contiguous tissue layers across sequential frames, in two planes, was applied to the movements of each subject in each taping condition. Differences of tissue movements and para-cutaneous translation in tissue boundaries were tested with repeated measures ANOVA.

Results

In 11 participants recruited to date, KT with lower tension significantly reduced para-cutaneous translation at the boundary of the skin and superficial fascia when compared to no taping (p=0.02). Para-cutaneous translation at the boundary of superficial and deeper fascia was significantly reduced when KT with lower tension was applied, in comparison with no taping (p=0.02) and KT with higher tension (p<0.05).
Lumbar flexion range was equal in all conditions.

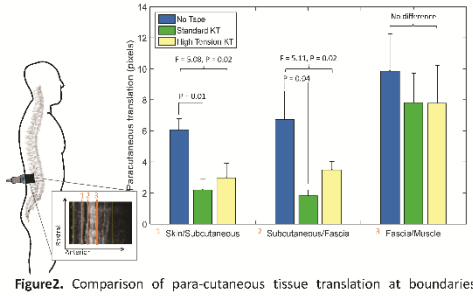

Figure2. Comparison of para-cutaneous tissue translation at boundaries during lumbar flexion. Error bars are standard error, n=11. 1mm=8 pixels.

Conclusions

Preliminary data yields two suggestions: (i) KT alters soft tissue dynamics during lumbar flexion, however what direction of change in tissue movement may represent a beneficial result from applying KT is uncertain; (ii) applying different tensions of the tape in therapeutic taping KT treatment may provide different results as the tissue effects differ systematically.

Implications

Dynamic ultrasound analysis provides direct evidence about the mechanism of KT action. The findings may, in future, be useful to explain observed effects. Our next step is to analyse collected data on spinal muscle activation, inter-segmental kinematics, and tissue layer specific strain.

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Ethical approval was granted by the Queen Mary Ethics of Research Panel (QMREC2014/24/3) on 08/04/2015.